IMPROVING AGENT BASED MODELING OF CRITICAL INCIDENTS

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ABSTRACT

Agent Based Modeling (ABM) is a powerful method that has been used to simulate potential critical incidents in the infrastructure and built environments. This paper will discuss the modeling of some critical incidents currently simulated using ABM and how they may be expanded and improved by using better physiological modeling, psychological modeling, modeling the actions of interveners, introducing Geographic Information Systems (GIS) and open source models.

Keywords: Agent Based Modeling, Critical Incident.

1 INTRODUCTION

A critical incident is "a relatively brief occurrence involving injury, loss, conflict, discovery or change of significant proportion, usually unscripted and unanticipated, with the potential to alter existing societal norm. Critical incidents are usually traumatic, threatening the bonds of trust that bind communities, but may be positive, initiating historic consequents."[1]. Critical incident analysis is a relatively new field of study. Fourteen distinct definitions of "critical incident" have been identified to date [2].

Agent based modeling has been loosely applied to the study of critical incidents, however no formal structure has existed for the application of any simulation methods to the subject. In January of 2008, at the inaugural meeting of the John Jay Academy for Critical Incident Analysis (ACIA), Goodman presented a model framework for Critical Incident Analysis [3]. The framework acts as a problem formulation, although it does not provide any specific solutions or suggestions of implementation – it is essentially a description of a general critical incident model at the "40,000 foot level".

There are currently a number of existing critical incidents models of that only have a partial conformance to Goodman's architecture. This paper discusses some existing model implementations and then suggests in a general way how they may be expanded using the framework provided.

2 BACKGROUND

Agent Based Modeling

"Agents are the people of artificial societies" [4]. Agents can also be developed to represent a threat. Batty [5] describes an agent as having the properties shown in Table 1. He states that a central feature of agents is their ability to communicate. This enables them to interact with each other as well as to sense and respond to their environment.

Table 1: Properties of agents[5].

Property	Meaning
Reactive	Respond in a timely fashion to changes in the environment
Autonomous	Exercises control over its own actions
Goal oriented/ proactive/purposeful	Does not simply act in response to its environment
Temporally continuous	Is a continuous running process
Communicative/socially aware	Communicates with other agents
Learning/adaptive	Changes its behavior based on previous experience
Mobile	Able to transport itself between spaces
Flexible	Actions are not scripted
Character	Personality and emotional state

Agents can be used to represent different classes of individual, such as violators, evacuees (a potential target) as well as emergency personnel. Each agent is autonomous. The properties described imply that an agent will be able to react to changes in its environment. They will obviously have the goal of preserving themselves over the course of the critical incident. The critical incident process will be happen over a period of time and the ability of the agents to respond will also have to occur over the same period.

Agent behavior may be based on previous experience. It may be assumed that the agent has prior knowledge or perhaps knowledge obtained during the critical incident being modeled. The agents must be mobile and have a degree of flexibility in dealing with their surroundings. They may be forced to make decisions based on their emotional state.

The underlying information used in model development consists of assumptions made concerning the properties of the agents. Quantitative aspects include the speed of movement of the agents in their domain, the number of different types of agents, the distance that they can “see” within their domain, etc. Qualitative aspects may include how the agents react to certain stimulus (do they “panic” for example, have they been “wounded”). ABM allows all of these characteristics to be programmed and changed, so a model can be developed iteratively.

Theoretical Framework for Incident Analysis

At the inaugural meeting of the John Jay Academy for Critical Incident Analysis (ACIA) in January 2008, Erik Goodman presented a model framework for Critical Incident Analysis [3]. Goodman established that any model of a critical incident would require the incorporation of the event itself, the demands it makes in the political arena, the influences of policy on the actions taken by the bureaucracy and adhocracy, and the resulting tactics that are fed back into the incident. The political arena consists of interaction between the government and the governed based primarily on trust. The bureaucracy and adhocracy consists of management and whatever responsibility they delegate to the interveners. Within the framework, the media is shown to influence all other elements described.

The critical incident itself is comprised of violators and their threat to the target as shown in Figure 1. The primary goal of this paper will be to discuss the modeling of the threat and the target, with some discussion of the tactics of the interveners (first responders) and the violators.

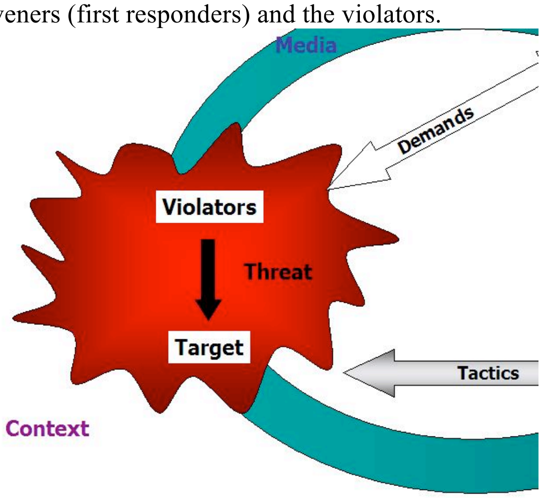

Figure 1:Critical Incident - Violators, Threat and Target [3]

Why Agent Based Modeling of Critical Incidents?

Agent based modeling is appropriate for the development of a simulation of critical incidents for a variety of reasons. In early studies, some necessary components of a critical incident model have traditionally been too complex to adequately model, so simplifications are made. For example, many evacuation models are based on hydraulic modeling of the movement of people, treating the flow of human beings as a fluid flow, even though human movement is clearly more complex. ABM allows these more complex behaviors to be modeled more realistically. In addition, critical incidents have interdependencies that ABM can make tractable. For example, in certain incidents the interaction of evacuees with interveners (first responders) must be modeled. These interactions may radically influence the behavior of both groups. As the evacuees and the interveners can be treated as different agent types and as different individuals with different skill sets, the programming of these types of interactions becomes possible.

Data are becoming organized into databases of finer granularity. This data can directly inform the way the agents are programmed. Computational power is advancing very rapidly and we can now compute large scale micro simulation models that would not have been plausible just a few years ago [6]. Once a model has been verified and validated, this computational power allows many other scenarios to be examined, and often these scenarios would simply be too expensive, time consuming and dangerous to examine using any method other than simulation.

3 DISCUSSION

A primary goal of a critical incident model is to model the event and the threat brought by the violators, the tactics of the interveners (first responders), and the target (physical human or both) as shown in Figure 1.

Models Currently Developed and Employed

Existing models involving the threats of smoke and explosives are discussed. How the specific threat to the population is developed in the model is discussed, as well as some of their current limitations.

Modeling Evacuation: Threats and targets are evaluated on an ongoing basis during the infrastructure design process. Infrastructure projects are one of the few cases where agent based models of can be used commercially. Fire in transit vehicles in underground stations and the subsequent evacuation of those stations are commonly modeled when new passenger movement systems are designed. A National Fire Protection Association Standard (NFPA 130) [7] is frequently prescribed so that proper fire protection and evacuation facilities can be provided for new systems. The standard requires that the results of an evacuation model are compared with results of a fire dynamics model that represents the heat and smoke threat of a subway train fire. In this way the threat to the target population is ascertained. Some of the evacuation models commonly used are agent based. These include Simulex [8], Steps [9], as well as others. A graphic taken from a Steps model run is shown in Figure 2 [10].

Obtaining data to validate station evacuation designs has proven to be difficult. Full scale tests are difficult to perform for a variety of reasons including expense and the requirement that the systems operation be interrupted. The adoption of security cameras in many stations allows video to be collected that could help validate evacuation models. Obtaining this data is difficult due to security and privacy concerns. Currently, most models are validated by comparing their results to those of hand calculations that make use of the hydraulic models developed by Fruin [Fruin, 1971].

Concerning evacuation time, five separate phases can be distinguished:

(1) detection time
(2) awareness time
(3) decision time
(4) reaction time
(5) movement time

Usually the first four are grouped together as "response time". [11].

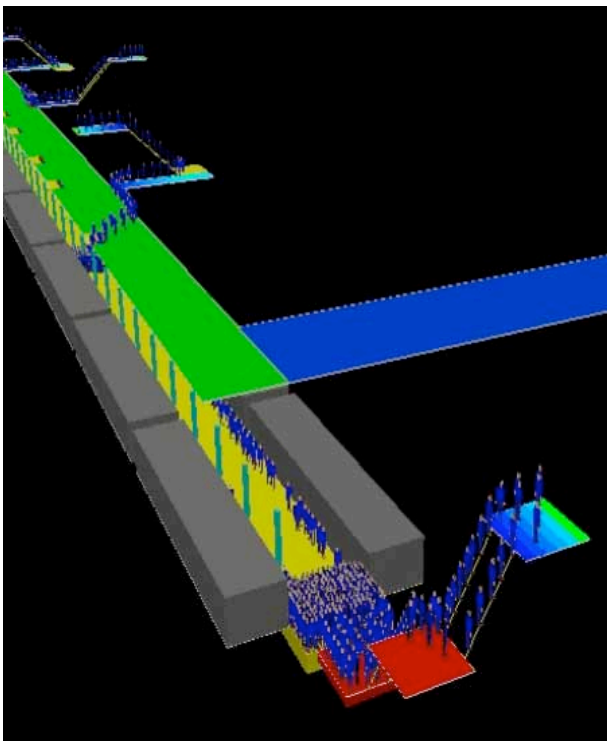

Figure 2: Steps Model [10]

Currently NFPA 130 does not prescribe a specific "response time" for passenger movement, although it requires designers to account for this time in calculations. This is an area that needs to be developed for a flexible critical incident model. Agents must be programmed to make decisions based on their awareness of what is going on in their surroundings, and what their peers are doing. NFPA 130 [7] does prescribed an evacuation time of four minutes from the platform and six minutes to a "point of safety". It is assumed that these egress routes will be clear of smoke during evacuation. This is verified by comparing the evacuation models with the result of models of smoke for the same egress times. The threat in this case is the fire growth and the products of combustion. There are a number of fire models currently available that will provide realistic conditions to obtain more accurate simulation of the interaction of this threat with the target.

Modeling "Panic": An agent based computer simulation model of mass egress from a stadium involving one or more attacks with Improvised Explosive Devices (IED's) was developed [12] using the Processing development environment. Anti-IED countermeasures were also modeled. These included improved real-time information systems to provide better guidance to exits, baffles to absorb shrapnel, and allowing egress onto the playing field.

The model assumes people are killed and injured in bomb blasts. However, the model is unusual in that it has an algorithm that determines when evacuating agents might "panic" and might be "trampled" during the evacuation. Panic behavior is generally not expected in crowd disasters. A full evaluation of the assumption that trampling would occur in a stadium bombing is beyond the scope of this paper, but it should be noted: "Although a precise accepted definition of panic is missing, usually certain aspects are associated with this concept. Typically "panic" is assumed to occur in situations where people compete for scarce or dwindling resources (e.g. safe space or access to an exit), which leads to selfish, asocial or even completely irrational behavior and contagion that affects large groups. A closer investigation of many crowd disasters has revealed that most of the above characteristics have played almost no role and most of the time have not been observed at all." [11]

Validation data was available from an evacuation test of PNC Stadium in Pittsburgh, PA. This limited data was available to check the model rates of flow through passageways and choke points within the structure. The program developers traveled to PNC park and studied its features extensively. They observed crowd movements before, during and after some events. They also corresponded with the chief of security for the facility.

The ability to carry out ABM in a highly visual and interactive manor allows the modelers to communicate ideas and theory to the public. The program was originally implemented in Netlogo. However, due to the long run times necessary it was recoded into Java and Processing.

Potential Model Improvements

Models can be improved in a variety of ways. These include adding more advanced physiological and psychological modeling of the target population, including the acts of interveners, and using open source models and methods so that the simulations can be reviewed by others.

Evacuation Models – Physiological Modeling: All the critical incidents discussed here share a common issue of mass evacuation in the face of different threats.
To develop a more general model, the concept of "response time" (the time it takes evacuees to begin to move) must broken down into its components, and depending on the threat, assigned different values.

In large-scale evacuations there is often limited egress width for evacuees to traverse. Disabled people may also slow the overall flow. The influence of these phenomena also should be included in any models.

Also, to the author's knowledge, no model takes into account the fatigue of the evacuees or the fatigue of the first responders. Some situations require extended evacuation times and possibly travel up stairs, such as in subway and ship evacuation. Data must be collected for these conditions as well.

The output of most advanced computer models is usually compared to the results of hand calculations based on the work of Fruin [13]. Fruin's work has been criticized recently by Fruin himself because the data he used was collected in the late 1960's. It is believed that pedestrians may travel at different speeds and densities based on a general increase in the rate of obesity since the 1960's. No data has been collected to verify these new assumptions, however. This lack of data needs to be remedied [14].

Evacuation Models – Psychological Modeling: Agents not only need to make decisions about when they should move away from a threat. In some cases, such as fire, they may choose to move through smoke or near the fire in order to escape. This is a fertile area for study. This would require an improved "simulated" situational awareness of the target. Studies have established that humans behave in many ways during critical incidents[15]. However, generally only evacuation is modeled.

As video is collected for security purposes, data about many potential critical incidents is being collected daily. For the most part this data is not being exploited to obtain information about the interaction between the threat and the target.

Action of Interveners: Data on first responder intervention is scarce. A relatively flexible model using discrete event simulation has been provided by Till [16], however more data concerning task times for first responders is needed. Data is needed to validate any model or sub model. The data collected may need to be refined based on the needs of model developers.

The presence of interveners will have a direct influence on the targeted population. What are they doing? Are they removing the threat, assisting with the evacuation of the targeted population? Will this give the targeted population better guidance. What influence will they have moving against the flow of people trying to reach a threat?

Introduction of GIS: An emerging issue in ABMs is the incorporation of GIS (Geographic Information Systems). In some cases it may be possible to integrate a map of the subject area as the "context" that the agents are operating in. For example, Netlogo has been used with the GIS software packages Geotools and Openmap to develop more advanced models. [17]. This would allow models to be run in very specific environments and could prove very useful in large scale engineering design.

Open Source: Many of the models that do incorporate both the threat and the target together are closed source and therefore also only subject to limited peer review. Mistakes and misconceptions are difficult to identify and discuss, as the model is essentially a black box. Developing a program using a common software architecture could help to establish a robust common basis for examination of evacuation during critical incidents. Making the source code available for the evaluation of all would increase confidence in any conclusions that were drawn using the software, making this portion of the critical incident model more robust.

The stadium bombing simulation mentioned previously has publicly available source code. This allows others to learn how it was implemented and can also help model verification, as other users will have the ability to look for logic errors in the software.

4 CAMPUS SHOOTING INCIDENT – SIMPLE EXAMPLE OF THE INTRODUCTION OF INTERVENERS TO AN ABM

In the case of the Virginia Tech Campus Shooting incident, the violator was an armed student who was targeting other students who fled or constructed barriers depending on their location. A prototypical shooting incident was developed and is shown in Figure 3 [18]. It is based on a modified sample program provided by the Netlogo package authors based on an epidemic spreading through a group of citizens [19].

In the modified model, a group of citizens has been randomly generated and placed within a grid space. Random obstacles have also been constructed within the space. The citizens have the ability to move throughout the space. If they "see" a shooter (a green figure) they flee. Fleeing citizens are grey. The gunman is moving throughout the space, selecting citizens at random and wounding them. Wounded citizens become immobile and their color is changed to blue. The gunman and the wounded students are presented as larger figures, to make their location more clear on a printed page. The gunman and two wounded citizens are circled in Figure 3.

As developed this model is trivial. In time all of the citizens will be wounded. However, in future iterations first responders may be added to the model. The number of first responders and their actions will play a significant role as to the possible outcome. They can assist the wounded or potentially fire back at the gunman.

The actions of the citizenry can also change. At some point they may all be "told" to take certain action via a wireless messaging system for example. What might happen if the gunman and his accomplices had this information too? These results will be examined as the model is developed further.

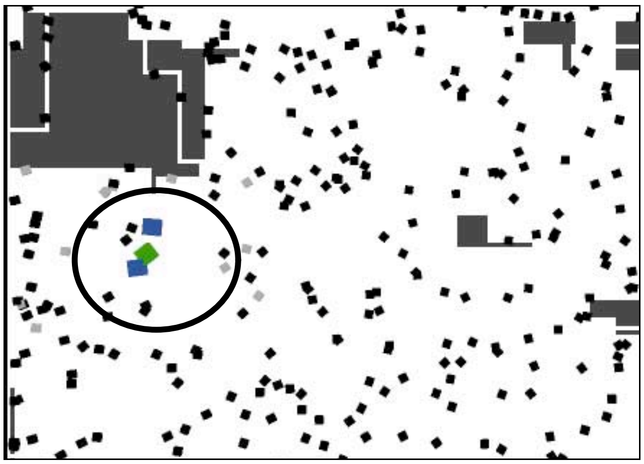

Figure 3: Campus Model with Single Gunman

5 CONCLUSIONS

It is suggested that ABM is an effective tool for the modeling the variety of emergency preparedness incidents, including ultimately those that are determined to be "critical incidents" as defined in the paper. ABM allows for the expansion of traditional models so that interactions and phenomena that are normally ignored in some modeling paradigms can ultimately be addressed effectively. Some of these phenomena were discussed and an example described to show that ABM allows the incremental improvement of models of critical incidents.

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