# A Simple Evacuation Modeling and Simulation Tool for First Responders

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***Abstract*—Although modeling and simulation of mass evacuations during a natural or man-made disaster is an on-going and vigorous area of study, tool adoption by front-line first responders is uneven. Some of the factors that account for this situation include cost and complexity of the software. For several years, Oak Ridge National Laboratory has been actively developing the free Incident Management Preparedness and Coordination Toolkit (IMPACT) to address these issues. One of the components of IMPACT is a multi-agent simulation module for area-based and path-based evacuations. The user interface is designed so that anyone familiar with typical computer drawing tools can quickly author a geospatially-correct evacuation visualization suitable for table-top exercises. Since IMPACT is designed for use in the field where network communications may not be available, quick on-site evacuation alternatives can be evaluated to keep pace with a fluid threat situation. Realism is enhanced by incorporating collision avoidance into the simulation. Statistics are gathered as the simulation unfolds, including most importantly time-to-evacuate, to help first responders choose the best course of action.**

***Keywords—evacuation modeling and simulation; incident management; emergency preparedness and response; geographic information systems; data fusion***

## I. Introduction

From modest beginnings, Geographic Information Systems (GIS) have become ubiquitous in today's emergency management (EM) environment [1], [2]. At the high-end of the spectrum are sophisticated, customized, commercial systems used in national and state emergency operation centers requiring a dedicated GIS support staff [3], [4]. At the county and local levels, commercial off-the-shelf products provide similar capabilities but are mostly supported by non-GIS professionals with other principal responsibilities [5], [6]. These tools may be augmented by the use of web browser and mobile mapping products [7]. Solutions usually exist for sharing most non-proprietary GIS data throughout the EM hierarchy. Evacuation modeling and simulation are not typically included in these GIS suites. Sometimes, plug-in modules may be added for this purpose at an additional cost. Custom, turn-key solutions, designed strictly for evacuation modeling and simulation, are also available [8], [9].

Developed by Oak Ridge National Laboratory (ORNL), the Incident Management Preparedness and Coordination Toolkit (IMPACT) is aimed at the first responder who may not have the budget or training to use commercial GIS products targeted at the dedicated GIS professional. In addition, it aims to overcome some of the shortcomings of web browser offerings such as the ability to add local content and the requirement for constant network access which may be problematic in the field. Funded initially by the U.S. Department of Homeland Security Office for Bombing Prevention as a counter-improvised explosive device (IED) tool [10], IMPACT has evolved to become a free, all-hazards software suite. Although IMPACT can be used for many EM functions [11], the focus of this paper is on its use in evacuation modeling and simulation.

## II. Design

From its inception, IMPACT was developed using free and open-source software components and copyright-free GIS data to allow its cost-free distribution as a government off-the-shelf product. The implementation language is Python and utilizes the wxPython graphical user interface (GUI) library [12], [13]. This allows IMPACT to be run on the Windows, Macintosh, and Linux operating systems while maintaining their native look-and-feel. Although IMPACT is primarily meant as a laptop tool for first responders working in the field, it can also be used on desktops and servers. Tablets may be accommodated by using remote desktop viewing software in conjunction with a server. GIS data may be shared with other software tools using a variety of file formats including ESRI shapefiles, Google KML, and spreadsheet CSV.

The GUI is patterned after tablets utilizing buttons that either execute a function or display a document. There are four panels labeled Tasks, Applications, Documents, and Maps which are similar in appearance. Fig. 1 is a screen-capture of the Tasks panel. A task is used to launch a simulation or generate a report. The Applications and Documents panels (not shown) organize shortcuts (aliases, links) to other programs and documents resident on the computer used for EM functions. Web bookmarks may also be placed on the Documents panel. Buttons on the Maps panel (not shown) open a map window for entering and viewing GIS content. With the exception of web documents and real-time data feeds such as current weather, all of this functionality is available in the field


Fig. 1. IMPACT user interface showing the Tasks panel.

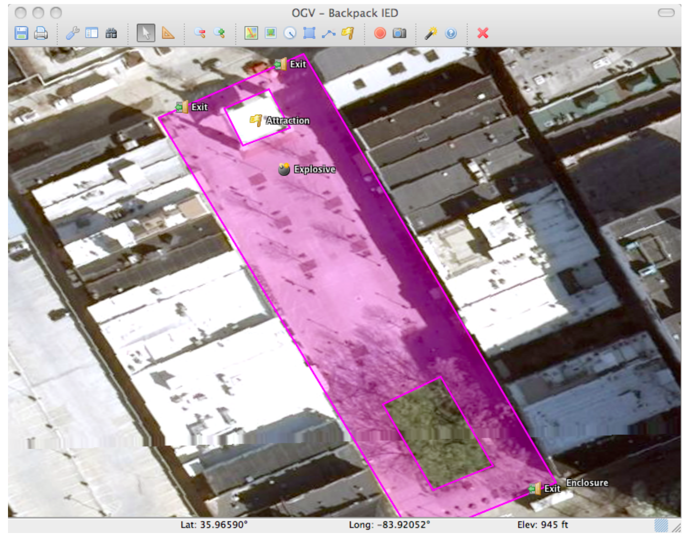


Fig. 2. Area-based evacuation setup showing bounded simulation area with cutouts, attraction point, exits, and IED threat.

without a network connection. This is achieved by preloading the laptop with the necessary GIS data. The data and map tiles are stored in a local database on the laptop. A detailed description of the software design may be found in [11].

IMPACT supports both area-based and path-based evacuation modeling and simulation suitable for use in a table-top exercise (TTX) or in the field during dynamic situations. Although not as sophisticated as dedicated evacuation modeling and simulation tools, IMPACT is capable of exploring basic questions about crowd capacity, number of exits, evacuation times, etc. In theory it can support crowds of any size, constrained only by computer memory. However, the intent is to explore small to mid-sized venues on-site in real-time. It is a multi-agent system utilizing Monte Carlo techniques and collision avoidance to achieve a higher degree of realism. Simulations may be recorded and played back later for comparison purposes.

Fig. 2 is a screen-capture of an area-based evacuation setup showing an outdoor venue with an enclosure bounding the simulation area. Any number of exits may be positioned on the enclosure border along with interior voids where agent movement is not allowed due to physical obstructions. The user may select the background location and map tiles (e.g., street, aerial, etc.) and use the built-in drawing tools to add these elements in a geospatially-correct fashion. These elements may be hidden prior to running the simulation if desired to reduce visual clutter. Parameters, such as initial crowd size, explosive size and time of detonation, and simulation step size, are exposed to the user through dialog screens. Once started, a running clock is displayed until all occupants have evacuated the area. Each agent has to self-evacuate after an event using the closest exit. An example will be presented in the next section.

When the simulation starts, the enclosure is first populated randomly with the number of agents specified by the user. A grid is used to determine if a cell is currently occupied or not. Then the agents begin walking toward the attraction point using a direction and step size drawn from Gaussian distributions. Collision detection is used to keep agents from passing through an occupied cell. Once the explosion occurs, the agents pick the closest exit in a direction away from the blast site and move towards it at a running speed. The agents are only rendered until they reach their chosen exit. After all agents have exited, the simulation stops and the total elapsed time can be noted. The user may modify the layout to explore variations in the enclosure shape and number of exits for example.

A path-based evacuation setup in shown in Fig. 3. It is similar to the area-based setup requiring a user to draw the enclosure and to position exits. However, exit routes are also needed since agent movement is constrained along them. To facilitate path drawing, a building floor plan graphic may be imported and sized to overlay a street map or aerial map view. Waypoints on the path represent attraction points to help agents locate the nearest path for evacuation after an event. These may be seen in the figure where the edit path mode is used to highlight the waypoints (large red circles). All of these elements may be hidden to reduce visual clutter during operation. Agent movement incorporates the notion of path width as well as collision avoidance for realism. The next section presents the results of a typical simulation run.

Populating the building enclosure proceeds as it does for the area-based example. This will take longer if there are many voids. Before the blast occurs, the agents move around randomly using a heading and step size from uniform and Gaussian distributions respectively. After the blast, each agent inspects each exit path to find the closest. Then it inspects each waypoint of the chosen path to find the closest and runs toward it. Once the waypoint is reached, the agent runs along the path toward the exit. Agents are not rendered once they come to the end of the path which may extend well past the building footprint if the user has drawn it that way.

In both types of simulation, collision avoidance between the agents adds an element of realism. This is implemented by tracking the latitude and longitude of each agent. An agent

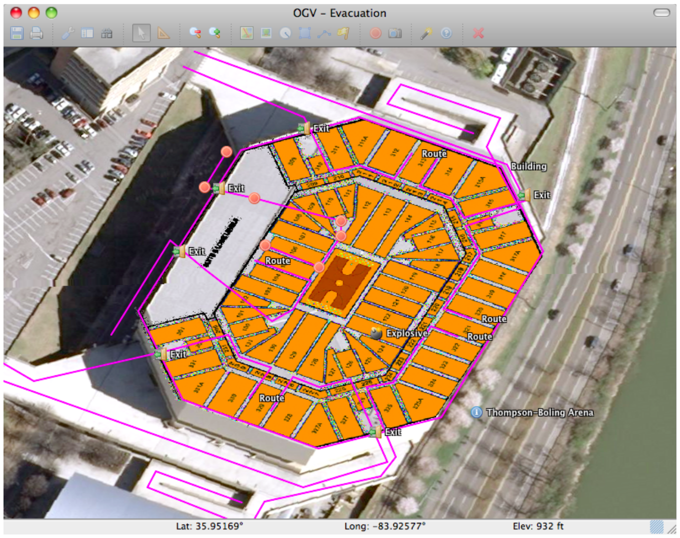

Fig. 3. Path-based evacuation setup showing user-drawn routes and waypoints for one route. A floor plan graphic overlays an aerial base map.

object generates a desired direction of movement and step size from random distributions constrained by the phase of the simulation (i.e., pre-blast, post-blast, etc.). It moves only if the resulting geographic cell is unoccupied, otherwise it waits for the next update cycle. The effective grid cell size is one square meter. This strategy results in computation times that increase linearly with the number of initial agents. An earlier method not involving a grid was abandoned since computation time increased as the square of the number of agents even though it was slightly more pleasing visually.

## III. Examples

To illustrate an area-based evacuation, a task has been programmed around a person-borne IED example. Fig. 4 shows the setup just after the simulation has started. Initially, the agents move towards a stage at the top of the figure. Variation is added to the direction and walking speed of each agent during each update to add realism. Collision avoidance is also employed so that agents are not allowed to pass through an occupied cell. At a user-selected time, an explosion occurs as shown in Fig. 5. Casualties are determined by the explosive charge size using the publicly-available DoD 6055.09-M specification and are indicated in red [14]. At that point, program logic in each agent object determines the closest exit in a direction away from the blast site. Movement is increased to a running speed and the agents progress through the exits after which they are no longer rendered. Fig. 6 shows the evacuation in progress. When all of the agents have exited the enclosure, the simulation stops. A clock records the total time of the simulation.

Fig. 4. Area-based evacuation start-up phase showing agents moving towards an attraction point (stage at top).

Fig. 5. Area-based evacuation blast phase showing detonation of an IED.

Fig. 6. Area-based evacuation exit phase showing agents exiting an area after an explosion has occurred. Casualties are shown in red.

In a similar fashion, a path-based evacuation is shown in Fig. 7 just after initialization with agents. When the blast occurs, as shown in Fig. 8, the agents must find the closest waypoint on the closest path to their current position and run towards it. Fig. 9 shows the clustering that occurs during this phase. The agents then move along the path towards the exit and finally out the enclosure. Fig. 10 shows the evacuation well underway. Once agents reach the end of the path, they are no longer rendered. Variation is built into the direction and speed with which the agents move to add realism. Thus they do not follow one another in tandem, giving each path a sense of width. Collision avoidance is also employed as before which slows down the exit process as it would in real life.

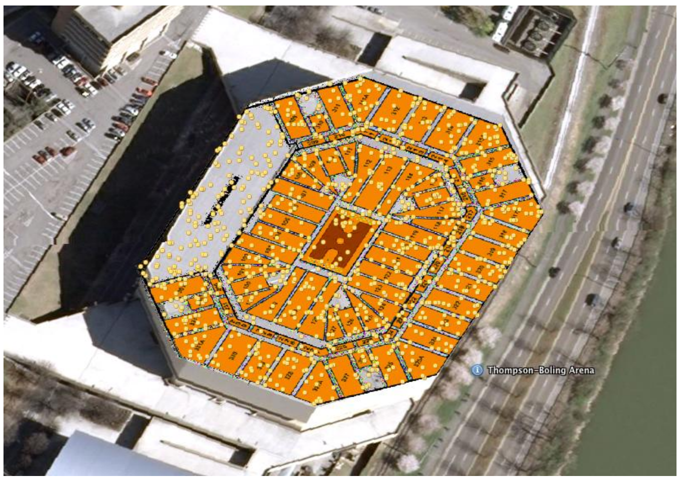


Fig. 7. Path-based evacuation start-up phase showing random agent movement within the building enclosure.

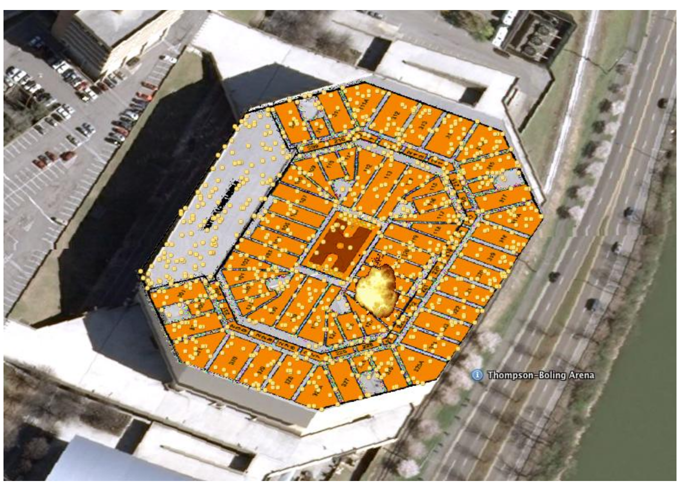


Fig. 8. Path-based evacuation blast phase showing the detonation of an IED.

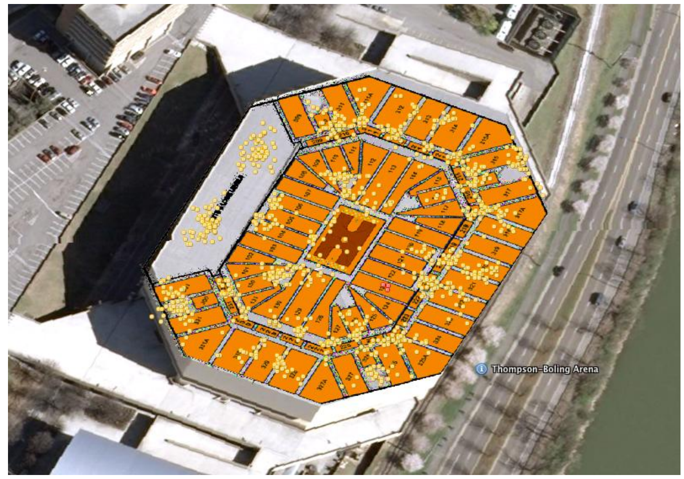


Fig. 9. Path-based evacuation route selection phase showing agents clustering around initial waypoints of a selected exit route.

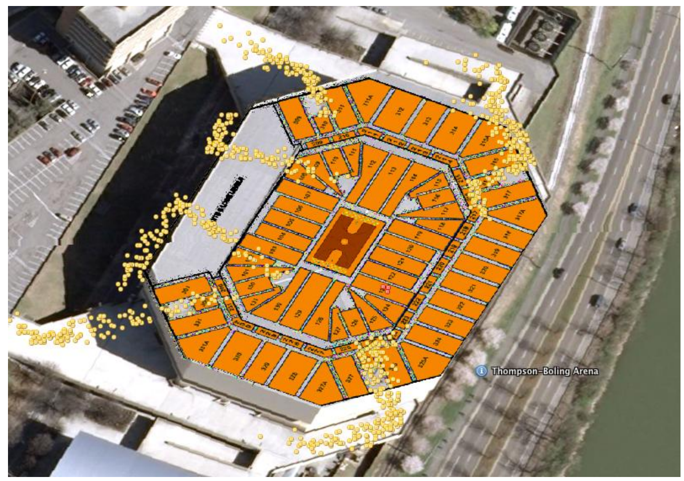


Fig. 10. Path-based evacuation exit phase showing agents exiting the building enclosure.

## IV. Conclusions

The two evacuation modules illustrated are currently rather simple in terms of their capabilities. For example, they do not support multistory buildings and do not incorporate a wide variety of human behaviors. More of the controls that govern agent movement need to be exposed to the user and additional output statistics need to be computed. No formal trials have been conducted yet to validate the evacuation times. Deviations will be largely due to human behaviors since the models are physics-based. These shortcomings will be addressed as development continues. A constant challenge will be to balance sophistication with ease-of-use for the intended EM user community. Feedback from first responders will help with this process.

This paper has focused on just the evacuation modules of IMPACT. Besides typical GIS functions, the tool also provides functionality that can enhance situational awareness. If a network connection is present, real-time weather and traffic feeds may be viewed that can influence evacuation decisions.

Also built-in are population and terrain elevation databases that can be used to make decisions about escape routes. Another currently available task module combines an area-based evacuation with bus transport away from the scene of an incident. The IMPACT framework is open-ended and extensible with regard to additional scenarios.

Initial users of IMPACT have included police, fire response personnel, EMS, and planners from the federal, state, and local preparedness communities. Federal homeland security agencies, state national guard units, and local bomb squads are using the built-in IED hazard tool to determine evacuation and damage distances. Local EMAs and fire departments are using the plume wizard to determine possible respiratory hazards downwind from a fire. Public health professionals are tracking the spread of contagious diseases and food-borne illness geospatially and temporally to determine mitigation strategies. As the list of users grows, suggestions for additional uses have increased. Feedback has been generally positive, especially with regard to ease of use and cost. Installation could be simplified and will be addressed as development continues.

IMPACT is certainly not the only GIS tool capable of the uses outlined in this paper. It is not intended to replace existing tools currently in use by the EM community. However, its low learning curve, ability to work with or without a network connection, and the fact that it is free makes it a valuable addition to the toolkit of responders first on the scene of an incident.

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