Modeling Society Reacting to a Nuclear Weapon of Mass Destruction Event

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Abstract. Individual connections between human beings often dictate where people go and how they behave, yet their representation through social networks are rarely used as measures of human behavior in agent-based models. Social networks are increasingly used for study of human behavior in disasters, and empirical work has shown that human beings prioritize the safety of themselves and loved ones (i.e., households) before helping neighbors and coworkers. Based on this assumption we have created a set of heuristics for modeling how agents behave in an emergency event and how the individual behavior aggregates into a variety of patterns of life. In this paper will present briefly our agent-based model being used to characterize the population's reaction to a Nuclear Weapon of Mass Destruction (NWMD) event in the New York City region. Agents are modeled commuting on work-day schedules before the explosion of a small (10Kt) nuclear device. After the explosion, agents respond to signals in their environment and make decisions based on prioritization of safety for themselves and those in their networks. The model methodology demonstrates how social networks can be integrated into an agent-based model and act as a basis for decision-making, and preliminary simulations show how agents potentially respond to a NWMD event with measurable changes in location and network formations over space and time.

Keywords: Agent-Based Model, Human Behavior, Social Networks, Emergency, Disaster Response, Nuclear Weapon of Mass Destruction.

1 Introduction

During emergencies and disasters people turn to family and friends for material and emotional support, and the structure and composition of these networks have real effect on how well a community responds and recovers from these events [1]. In the response phase of an emergency or disaster, social networks are used for information and physical support as individuals, groups, and families decide to evacuate, shelter, or find and give aid [1, 2]. Social networks in this phase of an emergency are very dynamic as people scramble to find safety for themselves and those they care for. Often ad hoc emergent groups form temporarily with short-term goals to find shelter or to provide aid and rescue [3, 4]. Research in this area is rarely available because the collection of social network data during the response phase is prohibitive and after-the-fact accounts can be unreliable due to trauma [5]. Agent-based modeling (ABM) can provide some insight into the dynamics of social networks in the response phase of a disaster when paired with empirical demographic and geographic data. To demonstrate this approach, we present our agent-based model being used to characterize human behavior after a Nuclear Weapon of Mass Destruction (NWMD) event in the New York City region. In what follows we provide a brief review of related work (Section 2), before describing briefly our model in Section 3. Next, we describe our verification efforts and discuss some preliminary results (Section 4), and we provide a brief conclusion in Section 5.

2 Related Work

Traditional social network analysis is limited to analysis of network ties with snapshots of the social network, but today the study of spatial and temporal effects on networks is quickly growing both in application [6, 7] and theoretical understanding [8-10]. Social networks also perform important functions in emergency and disaster events [1, 11]. Unfortunately, the collection, experimentation, and analysis of dynamic social networks that are not geocoded in social media remain a logistical challenge. One solution is to develop agent-based models (ABMs) that create virtual spaces in which agents are modeled interacting with their social and physical environments.

ABMs provide an experimental platform in which agents representing heterogeneous populations can act in a spatially explicit virtual world and have great potential for modeling complex adaptive systems such as cities and disasters [12, 13]. Within the simulated space of an agent-based model, individuals can form groups (i.e., create networks), interact within communities, and adapt with their environment [14]; for examples see [15-17]. They can also use place-based variables in their decision-making that have significant impact on emergency and disaster recovery such as physical exposure, local government, local planning, citizen participation, and social networks [18]. By adding the dimensions of space and time in social simulations, ABMs become powerful tools for experimenting with dynamic social networks.

Previous ABMs of emergencies and disasters that include social networks are limited [19-22]. Grinberger and Felsenstein's [19] disaster recovery model does not enable agents to travel through space; while Widener et al. [20] only models hurricane evacuations with a static social network. Wise [21] models fire evacuation and how social connections may impact the decision to leave, and Barrett et al. [22] models social networks that do not explicitly capture interactions in space. None of these models include network dynamics in their agent decision-making. Our model is designed to include location and social networks in the agent's decision-making process, and we will demonstrate how an agent-based model that integrates social networks with a spatially-explicit environment improves the realism of an emergency response simulation.

3 Model

3.1 Model Description

Our agent-based model has been developed to simulate the response of a population in the New York City region to a 10kt NWMD using the MASON Multiagent Simulation Environment [23]. This Java-based framework was chosen for its ability to import and create layers of geospatial data, so that agents can interact in a spatially-explicit environment as well as interacting with each other. The modeled area includes New York City, its commuter region, and extended areas in New Jersey, Pennsylvania, Connecticut, and Massachusetts to allow not only everyday patterns of commuting, but also represent external aid and rescue from unaffected areas to the area of destruction. The total population for the area at the time of the 2010 U.S. Census was 23,516,297 with 225,906 km of roads, as shown in Figure 1.

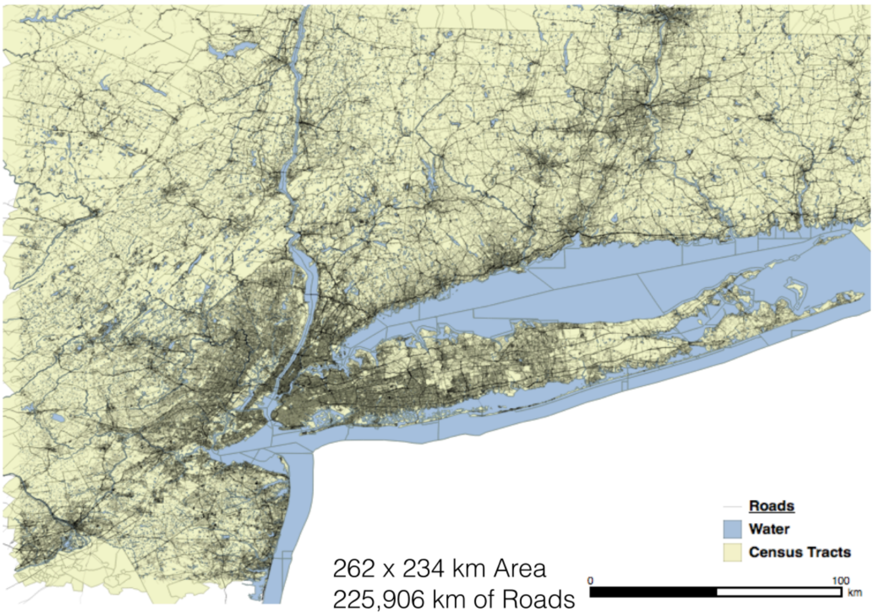


Fig. 1. Study area of New York City. Includes: parts of New Jersey, Pennsylvania, Connecticut and Massachusetts.

The agent population was synthesized from the 2010 U.S. Census data to generate a one-to-one representation of the entire population with over 23 million people. The agents are provided with realistic characteristics that include: 1) home, school, daycare, and work places located on the road network; 2) household size and composition; and 3) small-world social networks based on home, school, daycare, and workplace ties. The methodology for population synthesis builds on previously presented work [24]. A sample of a household network and its extended networks to school and work ties is shown in Figure 2.

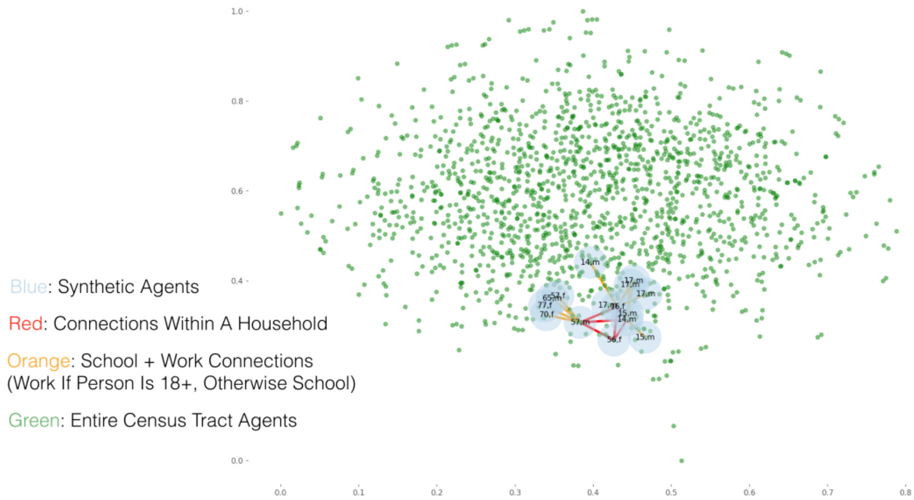


Fig. 2. An example of a household network aggregated from individual ties to home, school, and work connections.

In the model, each step represents one minute of real time, and at each step every agent is activated to make and implement their decisions, i.e., move towards a goal or stay in place. In the baseline agent behavior, i.e., prior to the weapon's detonation, agents follow daily schedules during a 24-hour day. They either stay at home or travel to work or school. For simplification agents initially only travel by car and do not utilize any alternative forms of transportation such as walking or taking the subway, train, or bus. Individual differences in the agent population with varying work-day time schedules and destinations create realistic patterns of commuter behavior (as we will show in Section 4). Figure 3 provides a sample of variations in agent daily patterns based on household compositions with most agents starting their routine at home at midnight.

In the agent-based model, the effects of the NWMD detonation are modeled as a ground burst and based on the publicly available reference, Glasstone and Dolan [25]. Model parameters specify the location, yield, and time of the detonation, and the model then implements a ground burst at the specified time. Our simulation scenarios are typically based on a 10Kt weapon in Manhattan detonated during the workday. Agents' health deteriorates depending on the weapon size and its distance from ground zero. Blast effects are represented in three zones based on agent health status: immediately killed, mortally injured, and injured, but likely to survive. Agent health is displayed as a change of color. Upon injury, agents begin to move away from the impact area at varying speeds. Mortally injured agents walk slower than those likely to survive (as we will show in Section 4).

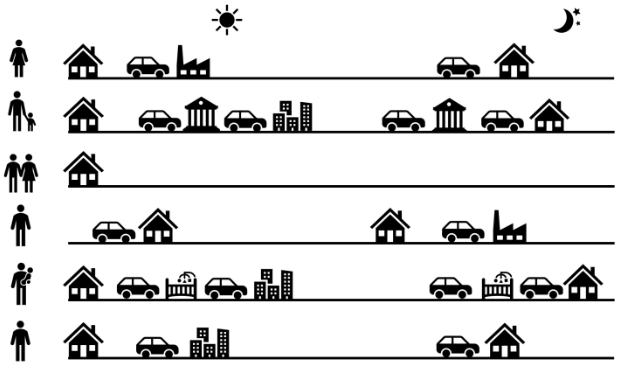


Fig. 3. Various patterns of commuting behavior representing daily routines of the individual agents.

In the model, the detonation of a NWMD in New York City causes agents to alter their normal behavior and daily routines. Agents whose health is directly affected or who learn that there was an explosion (e.g. via their social network) change their goals from the daily commuting schedule to finding safety for themselves and household members. Depending on the availability of shelter and agent knowledge, they will either choose to form ad hoc groups (i.e., emergent networks), shelter, or flee from the blast, fire, and radiation areas. Once they have achieved relative safety, they will search for, locate, and join members of their household network. Unaffected agents continue with their daily routines until they learn of the event, in which case they locate household members, adjust their commutes to avoid any evacuated areas, and return home. Agent behavior is currently modeled to represent only the first 24 hours after a NWMD explosion, however as we continue to develop, refine, and validate behaviors we will extend the simulation time period to days following the event.

3.2 Data Sources

As discussed earlier, the model includes both empirical data and data synthesized from empirical sources. The information about roads, population, schools, workplaces, and commutes was obtained from a number of U.S. Government websites. Table 1 shows the reference data for specific model representations.

4 Verification and Preliminary Results

Verification and validation of the population synthesis process was presented previously [24]. Basic verification of the model presented here included conducting code walkthroughs, profiling, and parameter testing (e.g. varying agent population size and seeing how this impacted commuting times) to ensure the model was working as intended. In what follows we provide some preliminary results of the model. First, we show in Figure 4 how agents travel from their home locations (Figure 4A) to their work or school locations (Figure 4B) based on a work-day activity schedule (as discussed in Section 3). We also show how agents respond to a 10kt NWMD event just south of Central Park in Figure 5 with zoomed in views of agents around Manhattan Island. In this figure we can see how affected agents are initially clustered around the detonation site (Figure 5A) and colored based on their health status, ranging from healthy (green), sick (orange), lethal (red), and dead (black). The greater the distance agents are from ground zero the greater their chance of survival. Over time, those that can, move away from the impacted area at varying speeds depending on their health status (Figure 5B). Not visible in Figure 5 are agents designated as first responders who initially move toward the affected area. As noted in Section 3, a NWMD event causes agents to alter their normal behavior and daily routines (e.g. commuting behavior and locations) which is shown in Figure 6. Here you can see that after the event a proportion of the population is fleeing the area and attempting to return home.

Table 1. Data Sources

Model	Dataset	Source
Land features and road networks	2010 U.S. Census Tiger Shape Files	http://www.census.gov/cgi-bin/geo/shapefiles/index.php
Agents	2010 U.S. Census Tracts	https://www.census.gov/geo/maps-data/data/tiger-data.html
Schools	U.S. EPA Office of Environmental Information	https://geodata.epa.gov/arcgis/rest/services/OEI/ORNL_Education/MapServer
Workplaces	2010 U.S. Census County Business Patterns	https://www.census.gov/data/datasets/2010/econ/cbp/2010-cbp.html
Commutes	U.S. Census Longitudinal Employer-Household Dynamics Origin Destination Employment Statistics	https://lehd.ces.census.gov/data/lodes/LODES7/

While not shown here, it should be noted that when the size of the population is increased, there are more agents commuting and this creates bottlenecks (i.e., traffic jams) along the road network. Moreover, as one would expect, increasing the number of agents significantly increases the simulation runtime. We attribute this to the higher computational demand caused primarily by the routing algorithm (in this case an A-Star algorithm) and social network interactions.

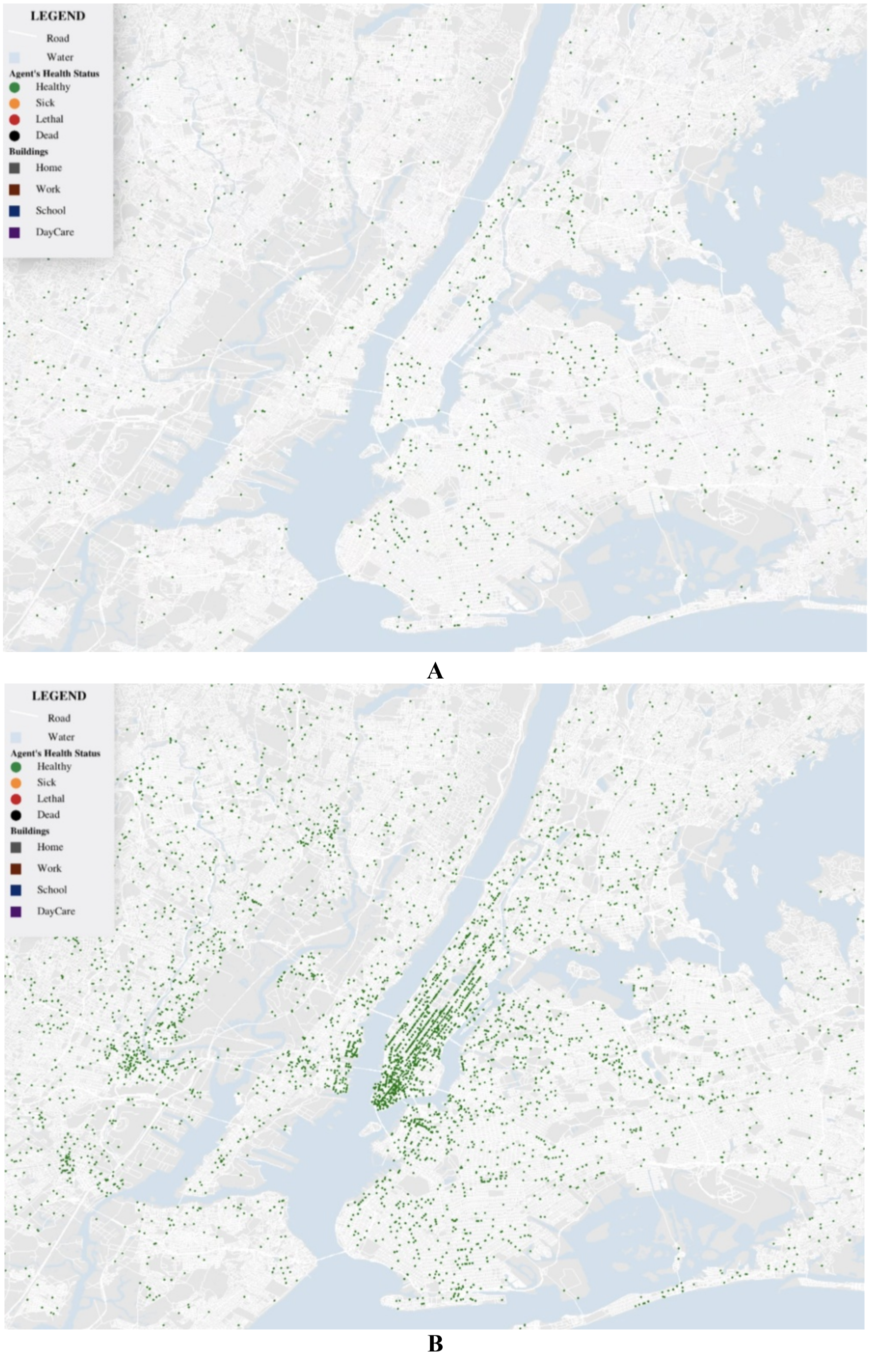
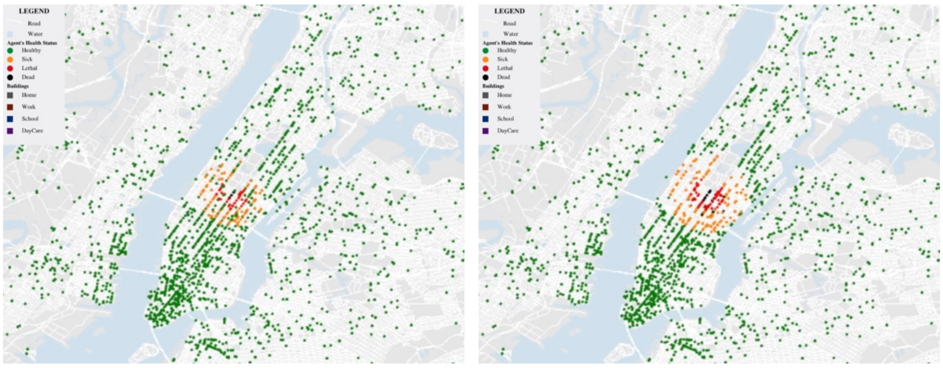


Fig. 4. A sample of agents' home (A) and work (B) locations in the New York City Commuter region.



A B

Fig. 5. Agents impacted by the NWMD explosion (A) and the resulting evacuation (B) during the work day.

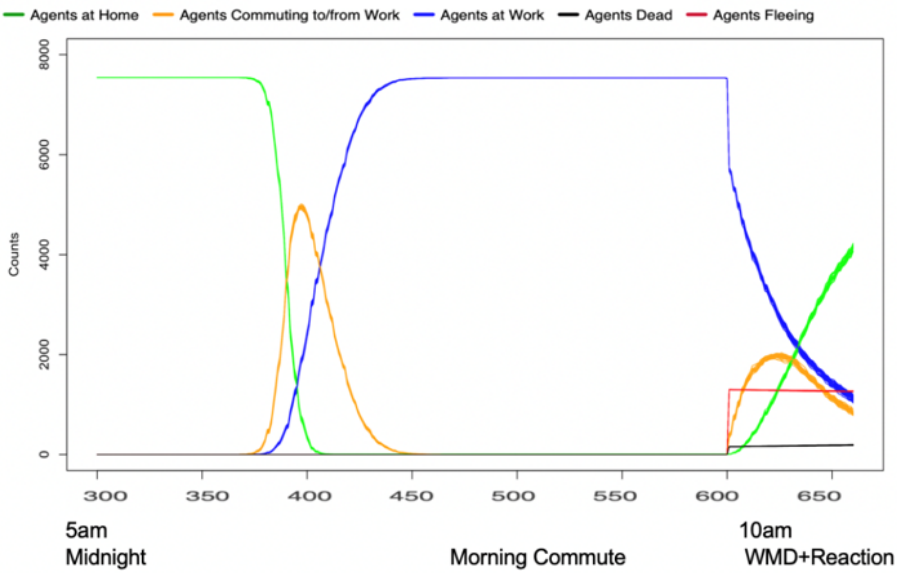


Fig. 6. Average results from 25 simulations when 7000 agents are simulated during a NWMD event.

Validation of behaviors and model results is still ongoing. Data from the Hiroshima and Nagasaki bombings, the only nuclear bombing events to date, are incomplete [26], however qualitative and quantitative data from past disaster evacuation studies are available and will be used. In our initial results, we have descriptive statistics on the number of agents at different levels of health, i.e., alive, sick, lethal, and dead. We are also in the process of improving the fidelity of interactions between first responders and victims, and the collection and analysis of these results will be presented at a future date.

5 Conclusion

In this paper we have briefly presented our agent-based model of societal behavior following a NWMD detonation. Our preliminary simulations show how it is able to simulate basic commuting patterns and initial movement away from the affected area after the NWMD event. By using a synthetic population generated from U.S. Census data we were able to create an artificial world populated by agents with sufficient heterogeneity to create realistic movement patterns and the social networks which play a vital role in disaster situations. While this is still ongoing work, our future research directions will be focused on improving post-detonation agent behavior by including: 1) ad hoc group formation and coordinated movement; 2) daycare drop-offs; 3) perception of the event from visual cues; 4) provision of immediate aid; and 5) information sharing using available communication networks. We envisage that the model will be extended to include first-responder agents providing aid during the first 24 to 48 hours after the event.

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