

Agent-Based Modeling and GIS: Exploring Our New Tools in a Disaster Context

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1. Introduction

In the immediate aftermath of a disaster, information can be invaluable to responders. Knowing where there are particularly vulnerable populations, damaged bridges, or disconnected power grids can hugely influence where and how responders focus their efforts. Further, knowing how passable different parts of the transport networks have become can impact how responders attempt to move around the space, potentially saving time and effort in a context when both are highly valuable. However, in crisis scenarios it is frequently the case that the environment is changing rapidly or has shifted considerably since pre-disaster information was gathered. Often responders are responding to either an unknown present or an even less familiar near future. In cases like these, it can be helpful to project the development of the crisis forward a short time, taking into account the quality of the data on which the projection is based. By combining geographic information with agent-based models (ABMs), researchers can gain better insight to how the crisis may develop, refining these projections as more information becomes available.

Combining GIS and ABM in this context is particularly powerful because it allows researchers to explore how boundedly rational individuals behave within a complex physical and social environment. ABMs allow agents to be endowed with multiple different interlinked kinds of heterogeneity, behaviors, and interactions, making it possible to investigate how different populations or cultures might respond to a crisis. The downside to this power is the need for data that is extensive, specific, and often frequently changing, making it difficult to provide the model with the information it needs. Further, accurate and current spatial data is a tremendous aid in humanitarian efforts, yet spatial data is frequently lacking in underdeveloped areas in particular. Even in cases where spatial data is available, its temporal resolution often lags behind the situation on the ground.

This work builds upon previous research, using an ABM developed to study civilian movement in the Haitian city of Port au Prince in the aftermath of the 2010 earthquake (Crooks and Wise, 2013). The model is combined with different historical data sets in order to explore how projection based on limited data changes as new information is introduced to the system.

2. Crowdsourced Data and Disasters

In recent years, new kinds of data production have become possible and increasingly widespread. There has been a tremendous increase in the popularity of both volunteered geographic information (VGI, Goodchild, 2007) and crowdsourcing spatial data (Howe, 2006) - that is, running bottom-up campaigns wherein volunteers map entire counties. Mapping efforts have been aided and organised by sites

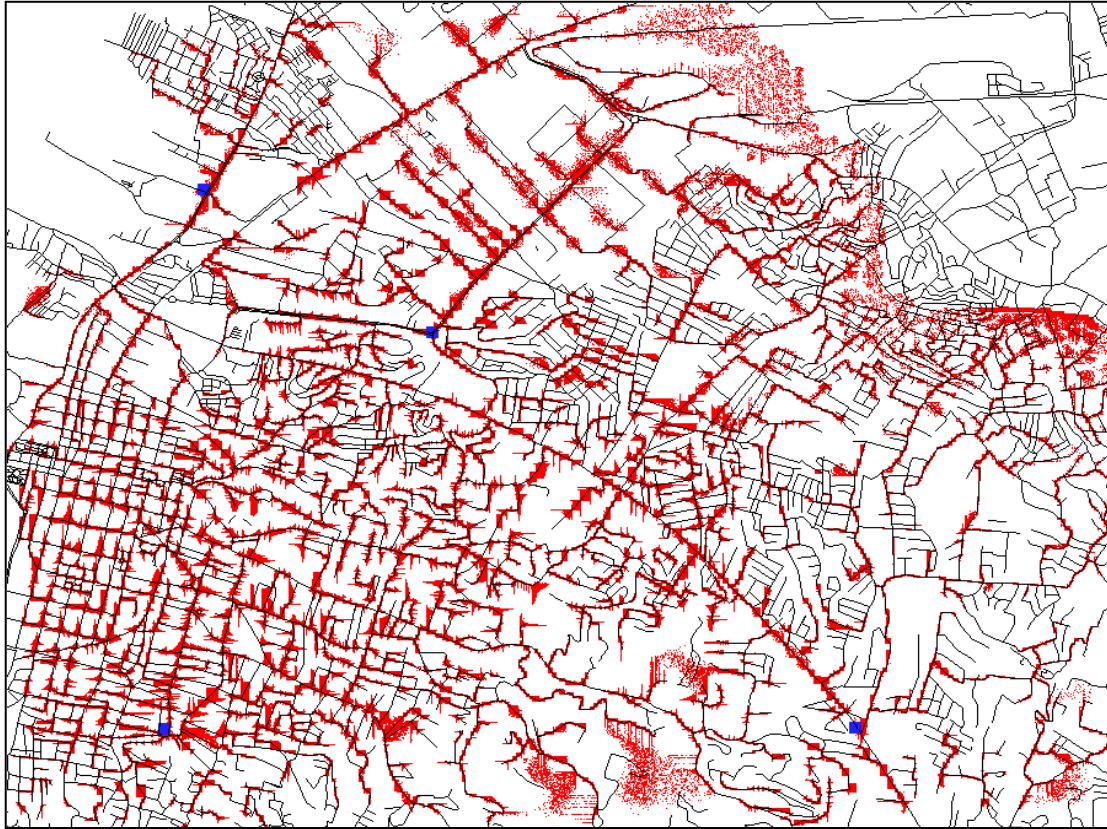


Figure 1. A sample instantiation of the model, where the blue dots represent aid centres and the red dots represent agents who are

including Ushahidi (2011) and CrisisCommons (2011), and both researchers and responders have shown interest in the possibility and reality of using crowds to rapidly map the infrastructure and devastation in disaster areas (e.g. Biewald and Janah, 2010, Zook *et al.*, 2010). Early research into the practice of crowdsourcing crisis events included a study of wild fires in Santa Barbara (see Goodchild and Glennon, 2010), and a great number of map mashups were used in a similar context (see Liu and Palen, 2010). However, the Haitian earthquake on January 12, 2010, prompted government agencies, technical experts, non governmental organizations (NGOs), and concerned citizens to jointly employ Web 2.0 technologies and crowdsourcing to aid the humanitarian effort in real time (United Nations Foundation, 2011). Within a few days of the earthquake, volunteers had produced maps of roads, buildings, shelters, refugee camps, and other geographic features, synthesising information from various pieces of satellite data to a new, operational map of Haiti which surpassed any existing map of the country (see Meier, 2011). The information provided by this combination of actors played a critical role in guiding response teams and minimizing the suffering of those affected. In the aftermath of the Haitian earthquake, crowdsourcing and social networks helped fill the information gap in a timely manner. The Haitian earthquake marked a new research frontier for disaster response (see Biewald and Janah, 2010), and represents an important moment for research as well as practice.

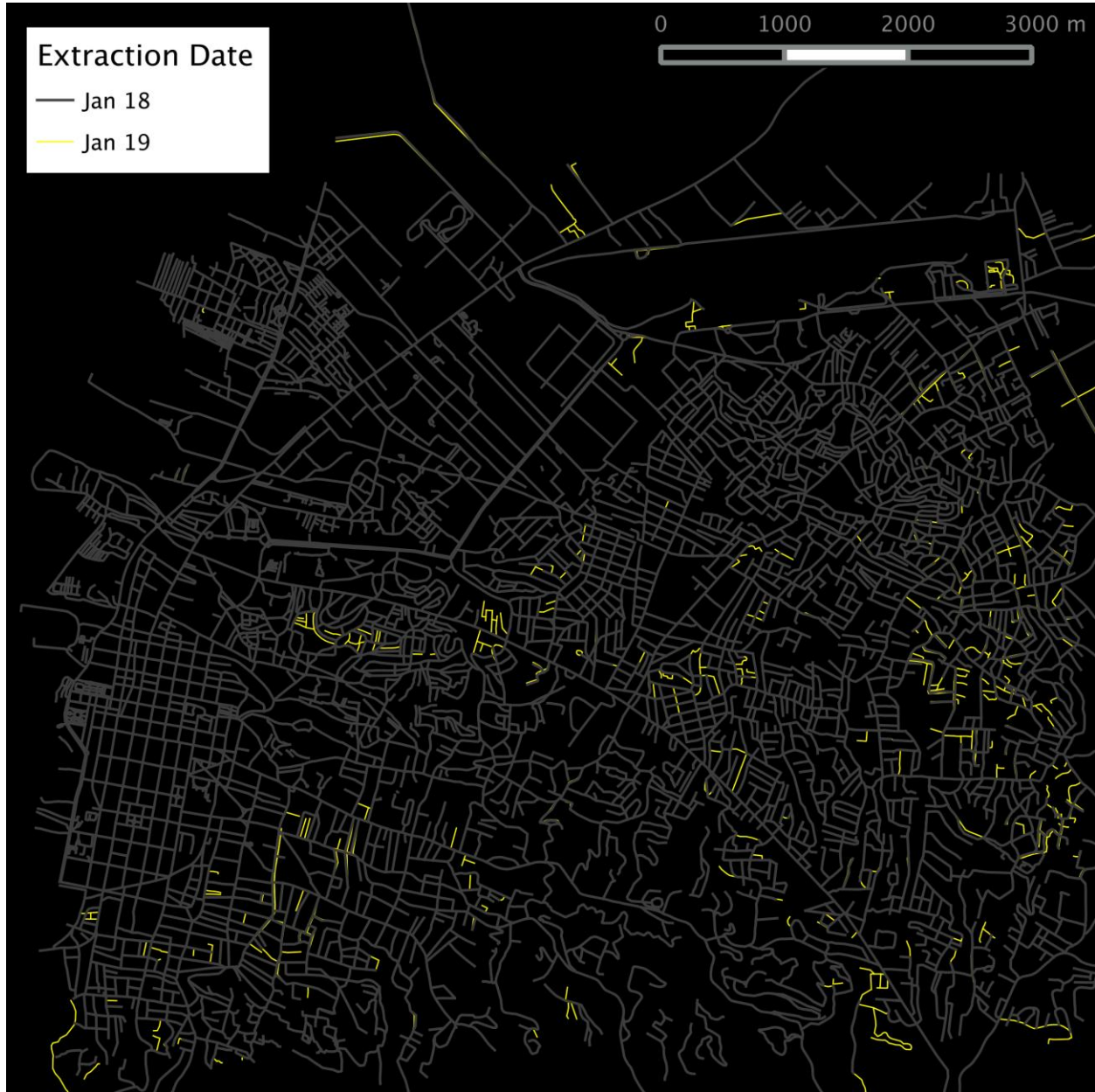


Figure 2. A visualization of the GeoFabrik extraction of the OpenStreetMap road network near Port-au-Prince, Haiti, where roads range in color from gray to yellow based on how soon after the earthquake they were added to the database.

3. The Model

While the specifications of the model itself are discussed more extensively in previous work (see Crooks and Wise, 2013), an overview of the system is presented here in order to give a sense of how the differing datasets impact the behaviors of agents and the development of the system. The simulation process begins by combining various types of demographic spatial information in

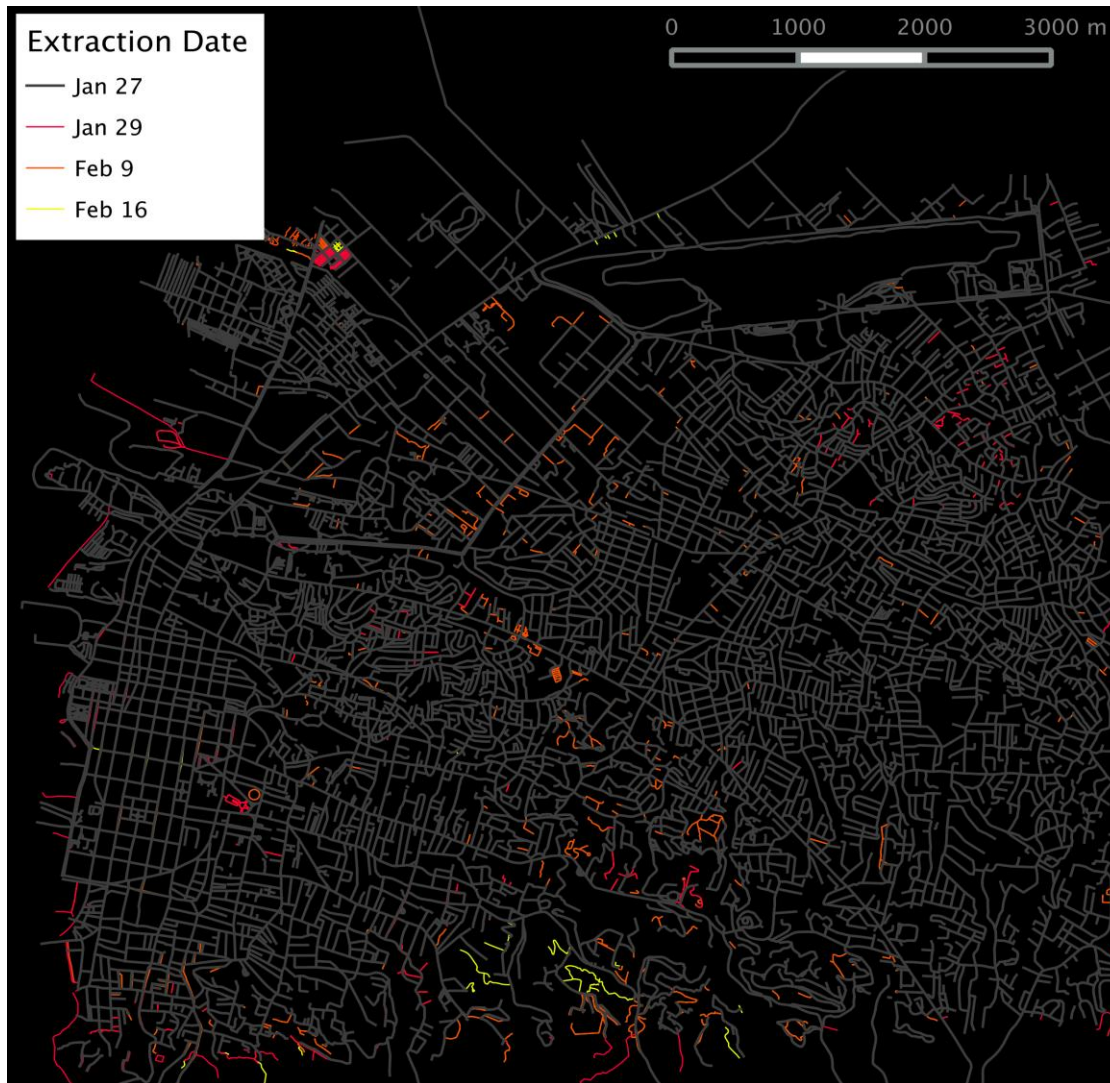


Figure 3. A visualization of the GeoFabrik extraction of the Ouest region of Port-au-Prince road network, where roads range in color from gray (the initial record) to red to yellow based on how soon after the earthquake they were added to the

order to create a synthetic population of individuals, each of which is embedded within a social network. The structure of this social network and the relationships between agents allow agents to share information with one another along their networks. Agents have varying familiarity with certain roads and geographical places, so that an individual will prefer to utilize known roads over unknown roads, all other circumstances being equal. The ability to capture the intersection of spatial and social phenomena is one of the most powerful aspects of ABM.

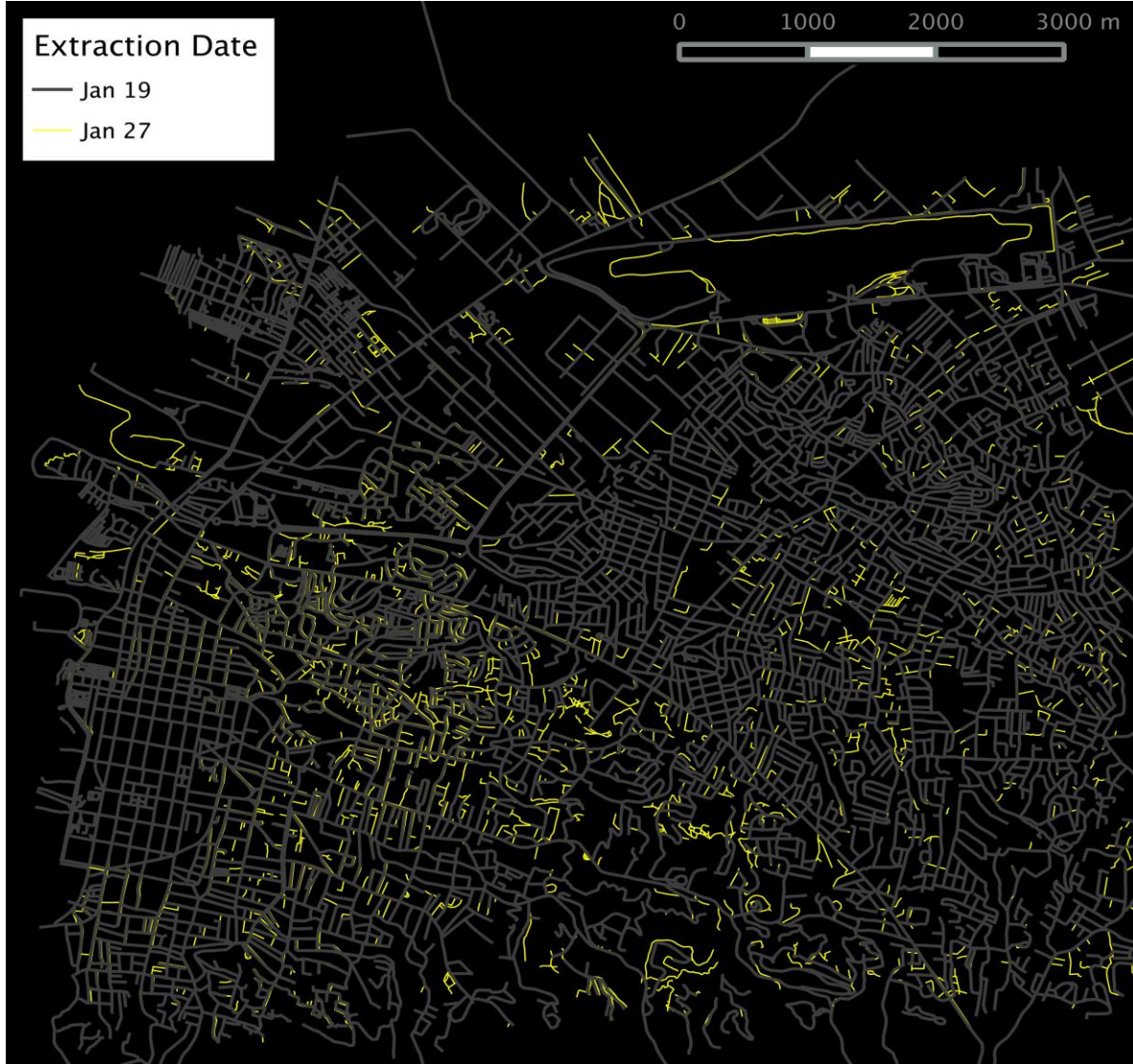


Figure 4. A comparison highlighting the difference between the records shown in the last of the GeoFabrik extractions on January 19 and the first of the GeoFabrik Ouest extractions on January 27.

Briefly, the agents in the simulation are oriented toward the goal of maximizing their energy, either by seeking out aid from one of the distribution points or by minimizing their activity. Agents communicate with one another about the availability of food at distribution centers, and make choices based on the information they have of whether to go to the centers or not. If they do decide to seek out aid, they expend energy walking to the centers and are constrained in how fast they can move by the density of the crowd around them. Agents wayfind on their known road networks, and generally do not have access to GPS technology. The simulation environment constrains their activities insofar as it provides an existing road network, which may contrast with the road network agents know, as a result of earthquake-related damage. Simple aid distribution center “agents” are also embedded within the environment, although their activities

are as simple as distributing out their limited supply of aid to the agents which come to their location in search of it. Based on this fairly simple environment and set of rules, the simulation produces pedestrian congestion which blocks access to aid and realistic patterns of aid center utilization.

4. Comparing the Impact of Different Road Networks

Because the simulation only permits agents to move through roads that currently exist, changing the road network changes the movement patterns and the resulting aid distribution utilization of the agents. Thus, the quality of the data and the time at which it was recorded impacts the quality of the results it produces. As mentioned above, crowdsourcing has grown into a more and more accepted part of disaster response and researchers have seen the quality of data increase drastically over a short period of time. However, at what point can the quality of the data be said to be “good enough” to support projection? How robust is the simulation to changes in the quality of data? To this end, this project explores the impact of substituting the road network as it was updated during the immediate pre-quake and post-quake period.

The simulation was initialized with six different road networks extracted from crowdsourced data at different points in the course of the volunteer mapping period. The results of the model are explored in light of these different road maps, as the individuals attempt to move through the environment based on their map-derived knowledge of the space.

Dataset	Energy	Food Leftover
GeoFabrik (Jan 18)	1732063215 (554143)	15.2 (2.2)
GeoFabrik (Jan 19)	1732124066 (689490)	14.7 (2.8)
Ouest (Jan 27)	1732148510 (552321)	20.1 (1.6)
Ouest (Jan 29)	1732659245 (594081)	20.5 (1.3)
Ouest (Feb 9)	1732432082 (634083)	20.4 (1.5)
Ouest (Feb 16)	1731946456 (676668)	20.2 (1.4)

Table 1. The energy and leftover food units associated with each of the road setups, presented as average value (standard deviation)

Depending on which of the six different road networks is utilized, the quality of the proposed aid stations seem to vary. While the overall energy rates remain fairly consistent regardless of the quality of the road networks, the quantity of food aid consumed actually decreases as the quality of the road map increases. This has to do with the assumption that agents make their decision of whether or not to expend the energy to pursue aid based on their knowledge of the environment: agents who know that the journey may be costly will not leave their homes in pursuit of it. Thus, as agents become more and more aware of the true road conditions, they are better able to assess the true cost/benefit analysis of a trip. The comparison highlights the importance of information to the decisions and resulting behaviors of individuals, and in particular the influence the changing data quality can have on the results of the simulation.

5. Conclusion

This research seeks to provide a sense of some of the capabilities and limits of the synthesis of GIS and simulation techniques. By combining the two, it is possible to push the boundaries of disaster response, moving from reactive to proactive handling of the situation. However, the perils of tailoring a response to misleading data must be considered. By exploring the interplay between a simulation and the data which supports it, this work seeks to advance explicit spatial simulation while avoiding its potential pitfalls.

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