Characterizing Social Community Structures in Emergency Shelter Planning

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ABSTRACT

During emergencies, it is often necessary to evacuate vulnerable people to safer places to reduce loss of lives and cope with human suffering. Shelters are publically available places to evacuate, especially for people who do not have any other choices. This paper overviews emergency shelter planning in disaster mitigation and preparation and discusses the need for better responding to people who need to evacuate during emergencies. Recent evacuation studies pay attention to integrating social factors into evacuation modeling for better prediction of evacuation decisions. Our goal is to address the impact of social behavior on the sheltering choices of evacuees and to explore the potential contributions of including social network characteristics in the decision-making process of authorities. We present the shelter utilization problem in South Carolina during Hurricane Florence and discuss an agent-based modeling approach that considers social community structures in modeling the shelter choice behavior of socially connected individuals.

Keywords

Evacuation Planning, Sheltering, Simulation, Social Network, Group Behavior.

INTRODUCTION

Emergency evacuations occur more often than many people realize, as a result of a variety of natural or man-made disasters each year (CDC, 2012). FEMA records that every year hundreds of times, many people face evacuation due to hazardous substances released from transportation and industrial accidents; the frequency is even higher for more common issues such as fires and floods. Furthermore, almost every year, people living along the Gulf Coast and along the Atlantic Coast are forced to evacuate due to hurricanes (FEMA, 2004). As a result, just before a hurricane makes landfall authorities need to decide which shelters will be opened and what their capacities should be, who should be told to evacuate, the timing of the evacuation orders and the method of disseminating that information to evacuees, and the suggested evacuation routes based on the forecasted speed, direction, and magnitude of the approaching hurricane (Li et al., 2012).

The evacuation and sheltering operations planning literature includes a variety of modeling approaches to address problems related to evacuation, such as evacuation traffic flow management (Bayram et al., 2015), shelter location (Chanta and Sangsawang, 2012), evacuee assignment (Ozbay et al., 2019), and resource pre-positioning (Arnette and Zobel, 2019). Additionally, recent studies have started to pay attention to integrating social factors into evacuation modeling for better prediction of evacuation decisions (Collins et al., 2017; Collins et al., 2018; Metaxa-kakavouli et al., 2018; Sadri et al., 2017a; Sadri et al., 2017b). These studies discuss the potential of detecting overall evacuation patterns based on the social network characteristics of individuals. Collins et al. (2017) argue that the consideration of the social factors in evacuation decision-making will contribute to the knowledge of sustainable community-based disaster preparedness and resilience.

With these in mind, this study seeks to highlight the following research questions:

Could social community behavior impact shelter choices of socially connected people who need to evacuate during an emergency?

and

Does the integration of social factors have significant improvements in the prediction of shelter preferences of individuals?

By exploring these questions, we seek to help authorities decide which shelters to open, based on their locations and their capacities, in order to better respond to the needs of affected people. To the best of our knowledge, no other study examines the shelter selection behavior of evacuees by describing them within a social network structure. This study will contribute to the literature by starting a conversation about the potential benefits of examining the impacts of social factors on sheltering choices, in order to improve the current shelter management efforts of the authorities.

In the remainder of the paper, we first explain shelter management problems and previous studies addressing planning efforts. We mention the primary decisions of affected people and management authorities before and during emergency evacuations in order to better describe the entire choice mechanism that needs attention. In particular, we focus on the shelter selection decision of evacuees. We then highlight the potential benefits of creating an agent-based model to simulate shelter choices of evacuees based on their social connections. Finally, we discuss possible manipulations to shelter attributes and social group structures in order to examine the shelter selection behavior of individuals who belong to a community, a specified group of people having high social connections. The paper concludes with a discussion of the intended next steps in the research effort, based on the preliminary results presented here.

BACKGROUND

Disaster Operations Management (DOM) is a worldwide consideration because much of the planet is repeatedly exposed to a variety of natural and man-made disasters. Problems in DOM are challenging for several reasons, such as the effects of severe damage from an event (e.g., on communities, infrastructure, and economies), uncertainties, resource insufficiencies, and conflicting interests of multiple stakeholders (Kocatepe et al., 2018; Rakes et al., 2014).

The DOM literature includes many studies about the sheltering decisions of authorities. In the pre-event phase of an emergency, the authorities need to determine alternative locations for emergency shelters, how many of them to open based on their budget, and how much space to provide for the people who will need to be sheltered. Shelter location selection depends on physical network conditions such as availability of alternative evacuation routes (Alçada-Almeida et al., 2009), traffic flow and congestion during the evacuation process (Sherali and Carter, 1991), and expected travel times to destinations (Li et al., 2012). Total evacuation time is one of the primary considerations of authorities since the time spent on the route increases the risk exposure (Reza et al., 2016). Furthermore, the authorities often need to decide on where to pre-position relief items, whether in local places or predetermined shelter locations (Salmerón and Apte, 2010; Arnette and Zobel, 2019). Although there can be significant uncertainty about evacuee behavior during the evacuation process, which increases its complexity, authorities consider many possibilities and strive to manage the overall process in the best possible way.

Evacuation planning and sheltering studies vary in terms of the scale of the affected region, the type of crisis, the modeling approaches, decisions, and selection of objectives (Murray-Tuite and Wolshon, 2013). Although some of the recent studies in the sheltering literature aim to identify the criteria and essential aspects that should be addressed in sheltering decisions (Nappi and Souza, 2015; Song et al., 2019; Xu et al., 2016), many others focus on decision-making based on some specific criteria (Arnette and Zobel, 2019; Coutinho-Rodrigues et al., 2012; Salmerón and Apte, 2010; Sherali and Carter, 1991). Additionally, there exist studies that specifically focus on the evacuation modeling and sheltering needs of population groups with special needs, such as aging populations or those with pets (Horner et al., 2003; Kocatepe et al., 2018). Our current study focuses on improving the efficiency of shelter opening decisions with respect to being in the proper place and of the right size, given the evacuation behavior of the affected population during an emergency.

Evacuee Decisions

Evacuee decisions significantly affect the performance of the evacuation processes (Madireddy et al., 2015), and the uncertainties in evacuees' decisions contribute to the complexity of sheltering problems (Zhao et al., 2017). Although the authorities put significant effort into informing individuals about what to do before, during, and after an evacuation, people are free to make their own choices. This means that they can deviate from the optimal

behavior according to Rational Choice Theory, which explains individual decision-making based on self-interests and personal preferences (Kuligowski & Gwynne, 2010), making the situation even more complicated. Typically, evacues need to decide on whether to evacuate or not, when to evacuate, where to evacuate to, and which evacuation path to take.

When an evacuation order is announced, it is defined as either voluntary or mandatory, based on the severity of the danger. If the evacuation is mandatory, then people living in specified zones are strongly encouraged to leave their homes. They can refuse the evacuation orders, however, and in such cases, they take full responsibility for their safety since there is no guarantee for receiving help due to the uncertainties in the region.

If people do decide to evacuate, then the critical concern becomes being sure they have a place to go to. Individuals will first evaluate alternative destinations (South Carolina Emergency Management Division, n.d.), considering options such as the nearest, soonest, or easiest safe destination (Barrett et al., 2000). Psychologists also mention that individuals tend to move to the familiar (Kuligowski and Gwynne, 2010). Destinations are commonly classified as one of three types, namely houses of friends or relatives, hotels/motels, and shelters, ordered from highest to lowest commonly preferred (Murray-Tuite and Wolshon, 2013). Although evacuees are primarily encouraged to go to hotels or to the homes of friends or family, many people still seek out shelters. Providing safe places for evacuation is the responsibility of local authorities, especially for the people who do not have any other alternative. On average, in the United States, shelter usage is about 15% of the evacuated population (Sorensen, 2000).

During the evacuation process, authorities provide detailed and up-to-date information about available shelters to go to, including information about location, utilization, and capabilities for special needs. However, in general, individuals are not directed to any specific shelters; thereby, the final destination choice is evacuees' (Murray-Tuite and Wolshon, 2013; Yin et al., 2014). In the literature, in order to decrease modeling complexity some studies make a straightforward assumption that people will try to evacuate to one of the closest shelters (Baharmand and Comes, n.d.; Bayram et al., 2015; Ozbay et al., 2019). Instead, in this study, we desire to show how shelter choices might be affected by social connections and group decisions, and we discuss if the integration of social factors cause a significant improvement in the prediction of individuals' shelter preferences.

MODELING APPROACHES

Emergency sheltering problems have garnered great attention from DOM researchers and they are frequently considered together with other evacuation management problems, such as evacuee allocation (Chanta and Sangsawang, 2012), evacuee routing (Coutinho-Rodrigues et al., 2012), and traffic flow management (Sherali et al., 1991). Shelter planning studies often investigate resource allocation to shelters before and during emergencies due to the need for a quick response to the large numbers of people evacuating to shelters (Arnette and Zobel, 2019).

In the shelter operations planning literature, researchers suggest a variety of deterministic and stochastic optimization-based models to address shelter planning decisions, including shelter opening, positioning, and capacity and resource allocation decisions. Examples of existing approaches that address various sheltering problems are the deterministic model of Sherali et al. (1991) for evacuation traffic management and shelter positioning, the two-stage stochastic programming model of Li et al. (2011) for sheltering network planning, and the scenario-based bi-level programming model of Li et al. (2012) for minimizing expected unmet shelter demand and total travel time. In contrast to such optimization-based approaches, some researchers prefer simulation-based models that are flexible enough to include expressions defining the moves of evacuees in certain situations. Simulations allow researchers to add uncertainties and changing behaviors over time, which reflects the evacuees' behaviors more realistically. There also exist studies that combine simulation and optimization methods, such as the iterative simulation-based optimization approach of Kimms and Maassen (2011a), which enhances the standalone optimization models by including the traffic flow limitations within a simulation environment, and the optimization-based simulation procedure of Kimms and Maassen (2011b) for examining evacuation-related traffic flows.

The shelter operations planning literature has traditionally paid little attention to investigating the behavioral aspects of individuals during disasters. However, it turns out that recent studies have started to argue that there is potential to predict evacuation behavior better if individuals are examined within their social network structure (Sadri et al., 2017). Vorst (2010) echoes this by arguing that modeling psychological variables improves estimates of human behavior during evacuations. Accordingly, researchers have started to examine the relationship between social network characteristics and the decision to evacuate, in order to incorporate social connections into the decision-making process. Sadri et al. (2017), for example, does this by analytically modeling the relationship between socio-demographics and social connections. Collins et al. (2018), in turn, look at this decision using a survey-based approach. Metaxa-kakavouli et al. (2018) also examine this relationship by analyzing social media

data. Such existing studies also commonly focus on particular human behaviors. For example, Vorst (2010) discusses the effects of heavy stress, denial of life-threatening events, inactivity, apathy, and childlike dependency on other people in different phases of evacuation. Moreover, Pel et al. (2010) include traveler information and compliance behavior in the evacuation model.

The substantial impacts of social connections on the decision to evacuate addressed by these studies motivate us to discover the effects of social connections on other sheltering decisions. Bearing in mind that the flexibility of simulations can represent social behaviors realistically, further investigation of the evacuees' shelter choices during emergencies is promising and deserved.

Grouping Behavior

During emergency evacuations, a significant proportion of the population usually organizes as small groups (Hofinger et al., 2014) since they seek support and orientation from group members (Von Sivers et al., 2014). Group members shift from their personal identity to their social identity, from which emerges the collective behavior of groups within the crowd. Accordingly, individuals' decisions will be affected by group decisions. Although individuals tend to self-select the closest shelters, their social group may cause them to choose another option.

Social communities are groups of people who have close social relationships, such as families, friends, and colleagues (Collins et al., 2017), but who are not necessarily close physically or geographically. During an evacuation, it might be reasonable to assume that people will organize as groups based only on their geolocation, but people could also try to move with their social communities, if possible. For this reason, identifying social communities could help decision-makers to improve evacuation planning strategies.

Examining the social connections within large-scale networks is an effective way of detecting social communities, and many practical analytical approaches are suggested for that purpose in social network studies (Capocci et al., 2005; Donetti and Muñoz, 2004; Faccin et al., 2014). These studies typically define community structures based on a closeness measure. Generally, social groups in the evacuation literature are referred to as having a size of 4 to 6 people (Oberhagemann et al., 2014; Von Sivers et al., 2014). Social networks include many irregularly shaped community structures, and many existing studies propose network or graph partitioning approaches to identify these irregularly shaped communities (Capocci et al., 2005).

Recently, researchers have started to study how social networks allow decision-makers to follow the preferences of social connections based on their perceptions of choice alternatives during the decision-making process (Sadri et al., 2017). These existing studies mainly focus on the decision to evacuate or not under evacuation orders (Collins et al., 2017; Metaxa-kakavouli et al., 2018; Sadri et al., 2017). Inspired by the promising contributions of social network investigation in these papers, we extend these previous results to consider the evacuees' shelter selection decisions instead of just the decision to evacuate.

EMERGENCY SHELTER UTILIZATION

Efficient disaster response and recovery necessitate careful planning for emergency shelter locations and capacities. However, shelter planning is based on making predictions under high uncertainty. On top of that, people tend to influence and be influenced by others if they are highly connected. We are thus motivated to explore if the authorities could have better insights and predictions about shelter utilization by examining the target population within a social network structure. Poor strategies on the part of the authorities could end up causing disparities in the evacuees' access to shelters, making it more difficult to ensure equitable allocation of resources. As an example of this, some emergency shelters in South Carolina were significantly over-utilized during Hurricane Florence.

Florence was a major hurricane that struck the southeastern United States in 2018, and emergency shelters were subsequently kept open in South Carolina for as long as 19 days, starting from Sept. 12th. Based on detailed shelter information obtained from the Red Cross' National Shelter System database, which contains information about location, capacity, operating days and other related information of all shelters operated in response to disasters, Figure 1 gives the county-based shelter utilization levels along with the number of shelters operated in South Carolina during Hurricane Florence. Specifically, the map in Figure 1(a) provides a color gradient based on the distance to the storm track, along with numbers indicating the average shelter utilization in each county. The maximum utilization value in this case, across all counties, was 2.5 (250% higher than the given shelter's capacity), and the lowest was 0.01. The map presented in Figure 1(b), in turn, is colored according to the counties' populations, with the associated numbers representing the total number of shelters that were operated in each county. Figure 1 clearly shows the high variation in utilization values, despite the correlation between the numbers of shelters and the counties' populations and risk levels (i.e., distance to the storm track).

The overcapacity problem faced in the high-risk areas begs the question of whether it is possible to improve sheltering service in the region via better prediction of shelter selection of evacuees. Group decisions might cause many people to insist on evacuating to the same shelter. Assuming that a specific region under evacuation orders consists of several social communities that need to evacuate to the emergency shelters, detecting social communities within the affected region and identifying the alternative shelters they might choose based on distance to shelters and social community decisions could provide better predictions about shelter utilization. This would, in turn, help with planning shelter opening and capacity decisions.

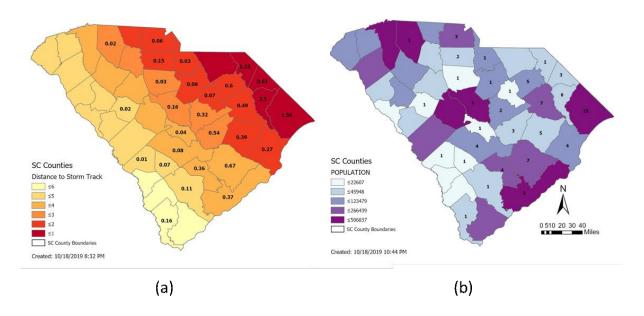


Figure 1. (a) County-based maximum shelter utilization (b) County-based number of shelters operating during Hurricane Florence in South Carolina

SHELTER ASSIGNMENT MODELING

As discussed above, we seek to examine different community structures within a region and analyze if shelter selections and utilizations are affected by those community structures. Agent-based modeling is a useful method for representing the complicated evacuation decision-making process by focusing on simulating the behaviors of adaptive actors who make up a social network and who have an influence on one another. The agent-based modeling approach has been widely used in many areas for behavioral analysis (e.g. Kennedy, 2012; Jiang et al. 2014; Yin et al., 2014). These models employ self-directed agents having different characteristics which lead to different behaviors (Yin et al., 2014). Agents socially and physically interact with each other and with their surrounding environment and adapt their actions (Fang et al. 2016). Accordingly, agent-based models allow mimicking heterogeneity of population behavior in the simulation framework. Moreover, such models can incorporate geographical information, and agents can be connected to define social network structures.

Gilbert (2019) defines microsimulation and system dynamics as the other two modeling approaches used in social sciences that bear comparison with agent-based models. Microsimulation models are advantageous in terms of using a set of agents created from a real sample. However, these models are not capable of considering how an agent will change its state over time; in other words, they neglect the change and adaptation in agent behavior. Moreover, microsimulation models do not consider the interaction between agents and are not capable of incorporating geographical information. System dynamics is a modeling approach for interacting variables which can link casual relationships. This approach works in the aggregate instead of with individual agents, so it is harder to model heterogeneity among individuals. The agent-based approach works better for the populations of behaviorally different agents (Gilbert, 2019), and it is this suitable to address complex, nonlinear and dynamic responses of individuals and groups during emergencies.

An agent-based model would allow for manipulating shelter attributes to examine shelter utilization, where *location*, i.e., the geographic position of the shelter, *capacity*, i.e., the specified maximum number of individuals that can stay in the shelter, and *service area*, i.e., a circle having a radius of the maximum travel distance allowed (assuming that the shelter is located in the center), are the main attributes of each shelter.

Modeling social connections between individuals requires having access to a social network representation of the

population. Social network structure is a different layer than the physical network structure, where physical networks connect individuals based on their spatial relationships. An example of the relationship between these two networks for a given group of individuals is illustrated in Figure 2.

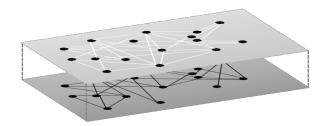


Figure 2. Social and physical network representations of a particular population

One way of creating a real social network is by using social media platforms such as Facebook or Twitter, where the connections can be identified based on the friendship/follower information of the users. In a practical sense, however, it is challenging to get access to each pairwise connection and to build the complete structure of such a network. Furthermore, because of confidentiality issues, location information can only be collected for users who actually choose to share their geographic location.

This implies that there could be value in having local emergency management authorities invest in building their own social networks, based on implementing a systematic information collection policy. Such a policy could request information from local individuals about a limited number of local individuals with whom they would want to be connected in an emergency, and this could be used to represent the social network structure of the corresponding population. Social group sizes of 4 to 6 could provide a sufficient number of connections to identify group (community) formations and build a representative social network of the affected population (Oberhagemann et al., 2014; Von Sivers et al., 2014). Different community structures could then be identified and input into the model by quantifying the community closeness based on the number of connections and locations of the members.

CONCLUSIONS

Recent evacuation and shelter planning studies have expanded awareness of the potential contributions of integrating social factors in the shelter decision-making process. In this paper, we questioned the impact of social behavior on shelter choices and started the conversation about its potential. Our broader research goal is to build on this overview of the problem and to investigate whether authorities might have better insights and predictions about shelter utilization by examining the affected population within a social network structure. This study is a very first step to bring social network structures into the discussion to observe the utilization of shelters based on evacuee shelter choices. Agent-based models are a promising approach for manipulating the evacuation process and observing how individuals select shelters and are affected by the decisions of their connections during emergencies.

One particular limitation for this research going forward is the difficulty of obtaining actual social network data. Creating a truly representative social network structure, perhaps through enacting local policies, would have high potential to improve the discussions and provide more realistic insights about the actual evacuation process. Thus far, the research effort only focuses on the sheltering choices of evacuees and discusses how shelter utilization could be improved by deciding which shelters to open and at what capacity. Different performance measures could also be considered, however, and solutions could be analyzed based on different objectives such as evacuee travel times or the selection of locations in need of additional shelters.

In the near future, we are going to develop a representative agent-based model and incorporate social network data to simulate the shelter selection behavior of the socially connected people during an emergency. Then we will apply it to real data to measure its relative effectiveness. We desire to examine different social network structures which will potentially bring evacuee groups to a different destination. By doing this, we are aiming to emphasize the value of creating representative social network structures for the populations in different locations that local emergency management authorities are responsible for. Furthermore, our future work will expand on discussions about individual and community objectives in shelter selection and how and why the actual final destination might deviate from the target destination. Additionally, we are planning to consider other accessible information such as census data and demographics to quantify the social closeness of the communities or compare differences in social structures in different geolocations. Such findings could help authorities open shelters on

time, in the proper place, and of the right size, given the evacuation behavior of the socially connected population during an emergency. This study will promote improvement of the current evacuation planning and shelter management policies and also contribute to build a sustainable community-based disaster preparedness and resilience.

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