AGENT-BASED MODELING OF EMERGENCY MANAGEMENT NETWORKS WITH PUBLIC MOBILIZATION AFTER A DISASTER

FINAL PROJECT REPORT

by

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16. Abstract

Local, state, and federal governments are responsible for managing disaster response with the goal of increasing disaster resilience of a community. This includes continuing adequate service levels for critical infrastructure sectors, reducing response time and cost, and ensuring the ongoing safety of the community. Complex emergency management systems typically consist of multiple organizations, including state Emergency Management Divisions, the military, and local Federal Emergency Management Agency (FEMA) offices. These systems also span multiple levels of government hierarchy, from local communities through the federal level of the United States. As we have witnessed, after a natural hazard or pandemic, the public will mobilize to fill the needs of the impacted communities that emergency response networks (ERNs) do not. Those that mobilize are called spontaneous volunteers. Spontaneous volunteers can often disrupt the operation of ERNs by duplicating work or spreading misinformation. On the other hand, spontaneous volunteers can also provide aid to ERNs when coordination is successful. This report summarizes an effort to simulate ERNs by using agent-based models that would allow ERNs to determine the best way to incorporate spontaneous volunteers within the official framework of the ERN.

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SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
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Acknowledgments

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EXECUTIVE SUMMARY

Local, state, and federal governments are responsible for managing disaster response with the goal of increasing the disaster resilience of a community. This includes continuing adequate service levels for critical infrastructure sectors, reducing response time and cost, and ensuring the ongoing safety of the community. Complex emergency management systems typically consist of multiple organizations, including state Emergency Management Divisions, the military, and local Federal Emergency Management Agency (FEMA) offices. These systems also span multiple levels of government hierarchy, from local communities through the federal level of the United States. Current in-place emergency response networks (ERNs) attempt to mitigate the impacts of a disaster as efficiently as possible, to return a community to normal operating conditions. Post disaster, communities are challenged to holistically function and respond in adherence with their emergency management protocols, which provide guidance on the intended actions/reactions of the public and the ERN. However, because of epistemic uncertainty surrounding public response and lack of public awareness of the in-place emergency management protocols, the public may not adhere to those expectations.

As we have witnessed, after a natural hazard or pandemic, the public will mobilize to fill the needs of the impacted communities that the ERNs do not. Those that mobilize are called *spontaneous volunteers*. Spontaneous volunteers can often disrupt the operation of ERNs by duplicating work or spreading misinformation. On the other hand, spontaneous volunteers can also provide aid to ERNs when coordination is successful. This report summarizes an effort to simulate ERNs by using agent-based models that would allow ERNs to determine the best way to incorporate spontaneous volunteers within the official framework of the ERN.

CHAPTER 1. INTRODUCTION

Local, state, and federal governments are responsible for managing disaster response with the goal of increasing the disaster resilience of a community. This includes continuing adequate service levels for critical infrastructure sectors, reducing response time and cost, and ensuring the ongoing safety of the community. Complex emergency management systems typically consist of multiple organizations, including state Emergency Management Divisions, the military, and local Federal Emergency Management Agency (FEMA) offices. These systems also span multiple levels of government hierarchy, from local communities through the federal level of the United States. Current in-place emergency response networks (ERNs) attempt to mitigate the impacts of a disaster as efficiently as possible, to return a community to normal operating conditions. Post disaster, communities are challenged to holistically function and respond in adherence with their emergency management protocols, such as the most recently developed Whole Community (FEMA 2011), which provides guidance on the intended actions/reactions of the public and ERN. However, because of epistemic uncertainty surrounding public response and lack of public awareness of the in-place emergency management protocols, the public may not adhere to those expectations. Experiences during Hurricane Katrina (Kates et al. 2006, Jha et al. 2010) and Hurricane Mitch (Comfort et al. 1999) showed that emergency management networks frequently have inadequate knowledge of the local community.

Communities at all levels (local, city, and state) have developed frameworks to inform the public about the potential hazards in their communities by using methods such as media and community events. This communication includes information about the hazard and how the local emergency management network will respond. Examples of these efforts are The Resilient Washington State Initiative (Washington DNR 2012), The Oregon Resilience Plan (OSSPAC 2013), Sandi Doughton's book *Full Rip 9.0* (Doughton 2013), and a recent article in *The New*

Yorker (Schultz 2015). Various cities have fully engaged and trained the public on how to respond at a community level, such as through Portland's Neighborhood Emergency Teams (NET), Basic Earthquake Emergency Communication Nodes (BEECN), and household preparedness programs (PBEM 2017).

Beyond efforts to increase public awareness of the potential hazards are community efforts to develop complex, multi-organizational emergency management networks. For instance, Washington, Oregon, and Idaho participated in "Cascadia Rising," a cross-state, multi-organizational, mock-emergency response exercise in June 2016. Since fall 2015, the West Coast has practiced what to do in an earthquake during the annual "Shake-Out" (USGS 2016). These exercises, while necessary to improve the efficiency of states' and communities' emergency management response at a high level, approach disaster recovery by using incident command, which is a top-down approach. Researchers at the Reassessment of Natural Hazards in the United States concluded that to ensure "sustainable hazard mitigation," disaster management must include community planning and public participation (Pearce 2003). Without local community involvement, disaster managers and planners cannot provide reasonable solutions to disaster-related problems (Pearce 2003).

The number of federally declared disasters in the U.S. has increased since the 1950s (FEMA 2016a). The Computing Community Consortium (2012) reported an estimated 7,000 disasters between 2000 and 2009 that totaled losses of over USD $1 million . These disasters affected over 2.5 million people both in the affected zones and across the U.S. Previous research has shown that the public will mobilize after a disaster to meet needs that the emergency management networks are not addressing. Public mobilization for post-disaster response has occurred after the 1985 Mexico City Earthquake (Dynes et al. 1990), the 1989 Loma Prieta

Earthquake (McEntire 2007), and more recently after the 2005 Hurricane Katrina (Rood 2012). However, these instances of public mobilization have been viewed as dysfunctional rather than helpful (Stalling and Quarentelli 1985). Since Hurricane Katrina, FEMA has developed two organizational training guides for collaborative approaches to disaster resiliency: the Community Emergency Response Team (CERT) and online training programs through the Emergency Management Institute. CERT comprises local first responders and firefighters. This program partners with fire departments to provide citizens with instruction and training for the first 24 hours after a disaster (FEMA 2016b). It is essential that these programs be integrated with te local ERN plans to avoid vulnerabilities at the interface between the ERNs and the public.

Currently, there is a disconnect between the public perception of emergency management operations and how those networks actually operate. Because of this disconnect and poor communication between the emergency management network and the general public, the public may mobilize to fill the needs of the local community. Those that activate are called *spontaneous volunteers*. Without any communication framework between the emergency management network and spontaneous volunteers, the two entities will not work to make the network more efficient. Rather, examples of spontaneous volunteers mobilizing have shown that they disrupt the efficiency of the network and often get in the way of the operation framework. By studying the network of communication and interactions within an emergency management network that follows disasters, it may be possible to better structure emergency management networks to incorporate spontaneous volunteers in a way that allows the two entities to work together. This project focused on building a framework to model an emergency response communication network, including spontaneous volunteers, responding to a large-scale disaster.

The goals of this study were to develop an agent-based model framework that can measure the impacts of stated public behavior on the response time and operability of the ERN as a result of interactions between the public and ERN, and to propose changes to the status quo that will improve the ERN's efficiency in responding. The international community has begun to recognize that flexible post-disaster response is necessary to address and solve challenges. Flexible ERNs need to consider the potential behavior patterns of local communities (Berke et al. 1993). Emergency responses to previous crises have demonstrated that regardless of the cultural differences between communities or nature of the crisis (i.e., natural disaster versus public health emergency), planning for emergency response is essentially the same (Berke et al. 1993, Tierney 1993).

CHAPTER 2. LITERATURE REVIEW

The frequency and intensity of natural disasters are increasing, and therefore the role of emergency response networks is growing increasingly important. However, these networks lack formal methods of communication among the various groups involved (Drabek, 1985; Waugh, 2006). In the United States, emergency response consists of organizations (including government agencies) at the local, state, and federal levels, non-governmental organizations (NGOs), and volunteers.

The role of the government in emergency response is constantly expanding (Kapucu, 2006; Waugh, 2006). As the agencies that make up the network grow and add responsibilities, the organizational structure has shifted from a top-down, bureaucratic approach to one that is more dynamic and collaborative (Waugh, 2006). As the emergency response system has grown it has become increasingly important to strengthen communication networks among organizations in order to facilitate more efficient collaboration. These communication networks can also be expanded to incorporate the volunteers that emerge around disaster scenes.

After a disaster, populations tend to converge on the disaster site (Fritz, 1957; Argothy, 2003). Motivations vary, but many studies have indicated that most of the convergers exhibit a desire to help victims of the disaster. (Perry and Lindell, 2003; Thomas and David, 2003). Fritz classified these volunteers as “The Helpers.” These helpers often fill gaps between the organized emergency management network and the needs of the affected community. Helpers assist victims by providing food, emotional support, and in some cases shelter. Multiple studies have indicated that these volunteers are integral in rebuilding communities and increasing resiliency (Dass-Brailsford, 2011; Waugh, 2006). However, to facilitate collaboration between emergency response organizations and emergent volunteers a network of communication is needed. To establish this network, an understanding of the organizational structure of the groups that make up the volunteers is needed.

Groups of people tend to organize in different ways depending on the situation. However, there are patterns in the organization of these groups. One example of this is the formation of leadership. A 2019 study found a correlation between an individual's ability to provide accurate information with a larger influence on the network (Nakayama, 2019). The study conducted experiments in which participants were placed in small groups and given a cognitive test. The participants were then asked multiple choice questions, and their responses were recorded. They were then shown other participants' responses and given the opportunity to switch their answers. Each group went through multiple rounds of testing. After the first round the participants were also shown the accuracy of the other participants' answers. The study indicated that participants copied others and that those who changed their answers improved their performance.

The study also tracked the centrality of each individual by using PageRank, a measure of network centrality that takes the entire network into account. The results indicated a correlation between an individual's information accuracy and his/her centrality in the network of participants. The individuals who performed well became group leaders over time. This centralization of individuals deemed trustworthy has also been noted in several other studies (Zhou, 2007; Zimmerman, 2005; Yolum, 2005). However, in less controlled environments the attributes that help establish a leader may be different than the ones observed in controlled studies. These studies indicate that spontaneous volunteers may organize into groups. By expanding collaboration between these groups and the existing emergency response network, it may be possible to strengthen the sense of community and increase community resilience to disasters (Barraket, 2013; Twigg, 2017).

Currently, the collaboration between emergency response organizations and volunteers is restricted by the organizations' inability to harness the volunteers to help recovery efforts. The convergence of people at a disaster site is often seen as disruptive and unwanted by most officials (Fritz, 1957; Twigg, 2017). As a result, the convergent population remains unorganized, which can be detrimental to emergency response efforts by slowing transportation. The current state of the emergency response system could be greatly improved by strengthening inter-agency communication and cooperation and by improving techniques to harness emergent volunteers. By continuing to move toward a dynamic and cooperative system, emergency response organizations could increase efficiency and minimize loss.

CHAPTER 3. METHODS

The framework was designed to model the communication network between emergency response organizations (EROs) and spontaneous volunteers who take part in the emergency response. The city of Corvallis in Benton County, Oregon, was used as a testbed. Due in part to its proximity to the Cascadia Subduction Zone, Corvallis has detailed plans for emergency response during large disasters. This plan is outlined in a public document that includes tables showing the organizations involved, their lines of communication, and the sequence of notifications that should occur immediately after the threat has been identified (Corvallis, 2009). This document also lays out the various responsibilities with which each emergency response agent is tasked. Using this document, along with input from the Fire Emergency Planning Manager of Corvallis, we were able to collect enough information about the city's emergency plan to develop a framework for modeling the communications following an earthquake (figure 3-1).

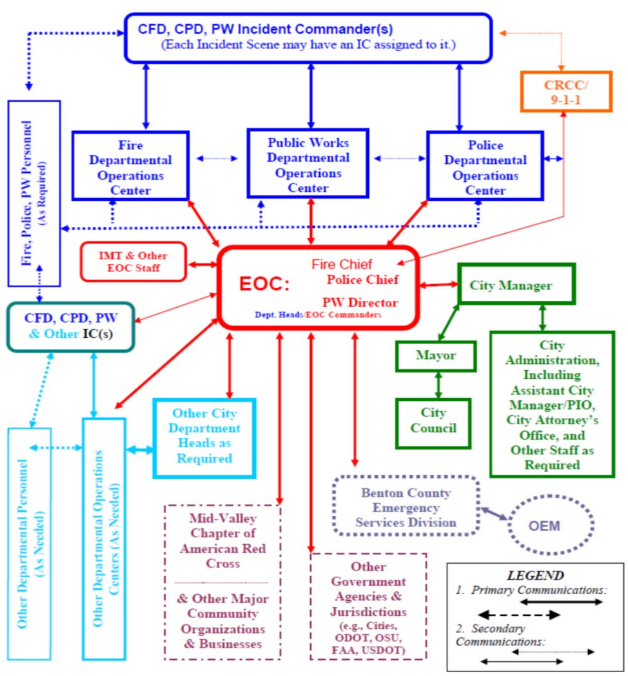

Figure 3-1. Emergency Operation Plan communication pathways

3.1. Implementation in NetLogo

The agent-based model was developed by using the commercially available software NetLogo. This software is a high-level integrated development environment frequently used to model dynamic emergent phenomena by using agent-based modeling (Wilensky, 1999). NetLogo was used to create a representation of the ERO's communications, similar to the one shown in figure 3-1. Each emergency response agent was represented by a node in the network. Agents were then linked together according to the communications network outlined in the Corvallis Emergency Operations Plan (Corvallis, 2009). Communication between the agents was simulated by linking the agents together and providing specific parameters on the links (timing, duration). The tasks assigned to each agency in the Corvallis Emergency Operations Plan were then assigned to each agent in the agent-based model. The tasks assigned included difficulty, level of danger, and duration. For this framework each agent in the emergency response communication network was categorized into one of three groups: leaders, managers, and field agents.

3.1.1. Leadership within the ERN

Within the emergency response network there is a group of agents who are responsible for enacting legislation and representing the people of the city. This group comprises the city manager, mayor, city council, and city administration (figure 3-2). These agents play a large role in the community's long-term recovery; however they are not directly involved in the actual response. Therefore, the framework focused on the manager and field agent groups, as they are the agents that interact with and affect spontaneous volunteers.

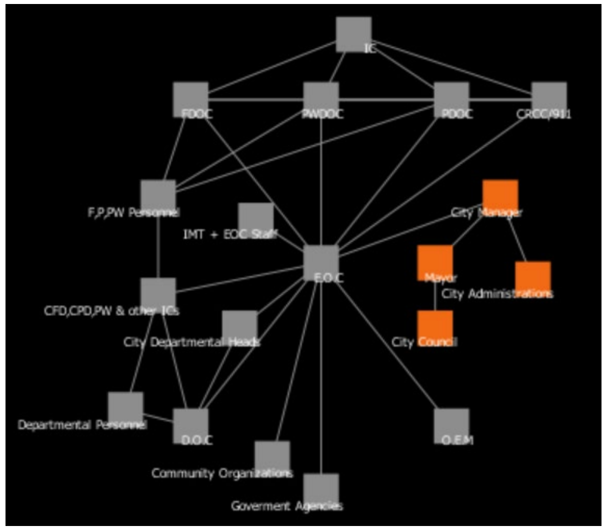

Figure 3-2. Simulating leaders in the ERN

3.1.2. Managers within the ERN

Within the network there is another group of agents in charge of coordinating the response effort (figure 3-3). This group includes the Public Works Department Operations Center (PWDOC), Fire Department Operations Center (FDOC), Police Department Operations Center (PDOC), and Corvallis Regional Communications Center/911. These centers are responsible for assessing the situation and dispatching Public Works Department, Fire Department, and Police Department personnel. The network also includes incident commanders, the Emergency Operations Center, the Incident Management Team, and other various city department heads and department operations centers. These agents' responsibilities include assigning tasks to field agents, procuring resources for the emergency response effort, communicating with state and federal agents, assessing the disaster's impacts, and managing volunteers. The EOC is responsible for managing the emergency response as a whole. Currently the EOC is also charged with assisting and managing spontaneous volunteers. Some situations require other city departments to manage the response; those departments are managed by other various departmental operation centers (DOC).

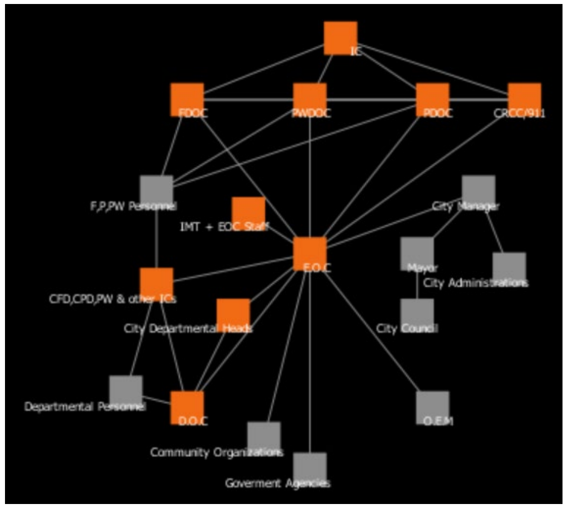

Figure 3-3. Coordinating agents

3.1.3. Field Agents

This group is tasked with protecting people, minimizing property damage, and surveying the damage to the city. It comprises personnel from local fire, police, and public works departments, Oregon Emergency Management, and various departmental personnel, government agencies, and community organizations (figure 3-4). Once the city's condition has been assessed by the management group, the field agents are assigned tasks to minimize the disaster's harm. These agents can be overwhelmed by large-scale disasters, which leaves a gap between the community's needs and the disaster response's capabilities. This gap may be filled by the spontaneous volunteers who appear in emergency situations.

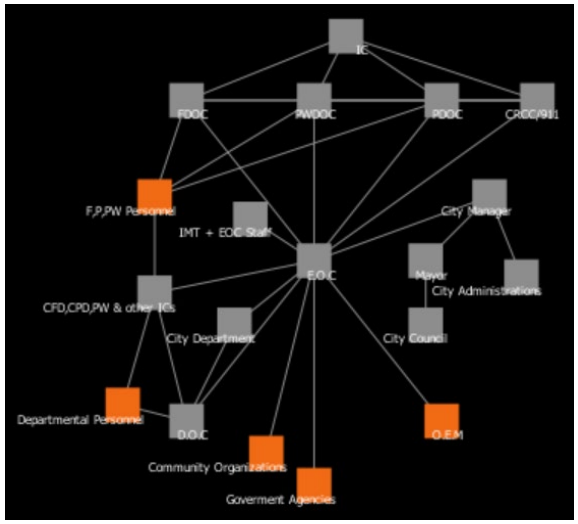

Figure 3-4. Field agents in the ERN

3.2. Execution of Simulation

The network was set up by using three text files named Nodes, Links, and Tasks (figure 3-5). These text files can easily be altered, which allows this framework to be adaptable. Each document contained information used to set up the framework; the Nodes and Links files contained information on where the nodes were located and which agents were connected. The Tasks document contained information on the tasks that the agents needed to complete, as well as the length of time required. These documents were then read by a function named Setup.

Within Setup, the documents were used to create the network, an agent representing spontaneous volunteers, a list labeled Tasks, and a second list labeled Task Dictionary. The Tasks list contained a variable number of tasks that were represented with lists containing two numbers, one that corresponded to the Emergency Support Function (ESF), which established which agents were responsible for each type of task, and one that contained a task number that was used to look up specific tasks within each ESF. The Tasks Dictionary contained lists that were used to store information about each task. These lists contained the mean and standard deviation of the random distribution used to generate how long each task took to complete. They also stored which agents were responsible for each task, and what tasks, if any, would follow.

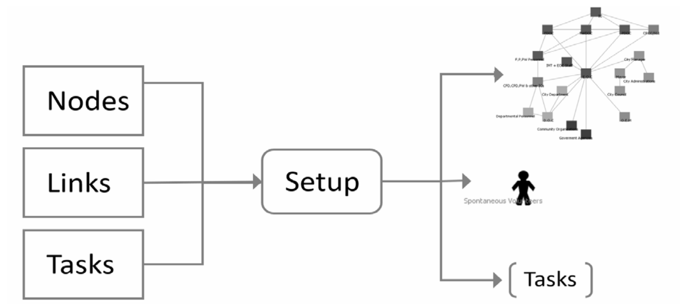

Figure 3-5. Network set-up in NetLogo

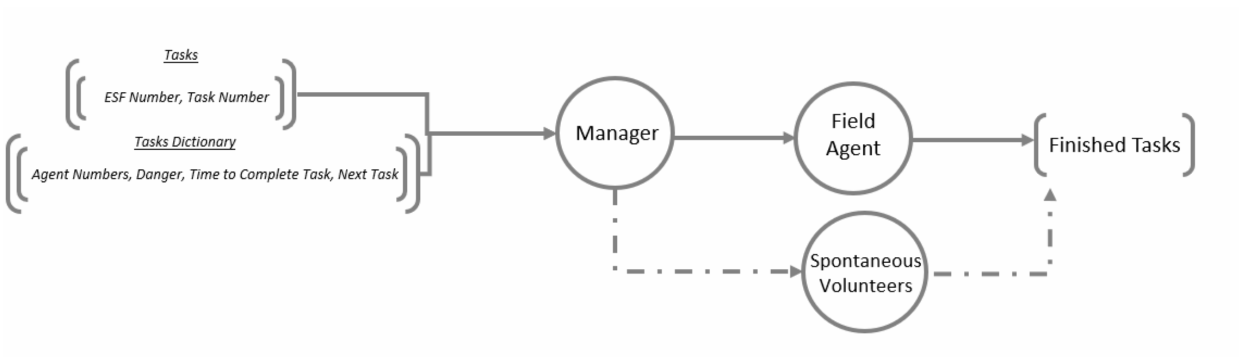

Figure 3-6. Coordination between tasks and agents

Once set-up had been completed, each manager agent had access to the Tasks list and the Tasks Dictionary. Each manager agent then read through the Tasks list and selected tasks that matched the ESFs for which the agent was responsible. The manager then sent the task to the Field Agent. The Field Agent spent time completing the task and, once finished, added the task to the finished list. The Manager could also be set up to assign specific tasks to spontaneous volunteers. This framework also allowed each manager to send some tasks to spontaneous volunteers. The spontaneous volunteer agent used the danger rating to calculate the chance of injury. If a volunteer was injured, another task was added to the Tasks list. Field Agents and volunteers then sent the finished tasks to a list labeled Finished Tasks.

By measuring the amount of time needed to complete the tasks assigned and the number of tasks completed, this framework could be used to determine whether assigning some tasks to spontaneous volunteers would increase the network's efficiency.

CHAPTER 4. RESULTS, CONCLUSIONS, AND FUTURE WORK

This framework allows users to test what communication framework maximizes the benefits of incorporating spontaneous volunteers. These benefits can be quantified by the efficiency of the network itself. The model has the capability to measure the timing of activating and completing all of the tasks within the network.

By modeling communications between spontaneous volunteers and emergency response organizations it is possible to identify what lines of communication would allow spontaneous volunteers to be the most effective.

This framework could be improved by accounting for different methods of communication. Possible communication strategies include incorporating pre-existing community groups into the communication network, which could possibly help better facilitate communication between the emergent volunteers and the local emergency response. The possibility of communication through social media should also be explored.

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