ABSTRACT

Title of Document: IMPROVING THE TIMELINESS AND RESPONSE TO AN AEROSOLIZEDANTHRAX ATTACK IN THE METROPOLITAN WASHINGTON, D.C. REGION

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Our research was conducted to improve the timeliness, coordination, and communication during the detection, investigation and decision-making phases of the response to an aerosolized anthrax attack in the metropolitan Washington, DC, area with the goal of reducing casualties. Our research gathered information of the current response protocols through an extensive literature review and interviews with relevant officials and experts in order to identify potential problems that may exist in various steps of the detection, investigation, and response. Interviewing officials from private and government sector agencies allowed the development of a set of models of interactions and a communication network to identify discrepancies and redundancies that would elongate the delay time in initiating a public health response. In addition, we created a computer simulation designed to model an aerosol spread using weather patterns and population density to identify an estimated population of infected individuals within a target region depending on the virulence and dimensions of the weaponized spores. We developed conceptual models in order to design recommendations that would be presented to our collaborating contacts and agencies that would use such policy and analysis interventions to improve

upon the overall response to an aerosolized anthrax attack, primarily through changes to emergency protocol functions and suggestions of technological detection and monitoring response to an aerosolized anthrax attack.

IMPROVING THE TIMELINESS AND RESPONSE TO AN AEROSOLIZED ANTHRAX ATTACK IN THE METROPOLITAN WASHINGTON, D.C. REGION

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Centers for Disease Control and Prevention (CDC)
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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AABB TF – American Association of Blood Banks Interorganizational Task Force on Domestic Disasters and Acts of Terrorism
APA – Aerosol Particle Analyzer
APDS – Autonomous Pathogen Detection System
ARC – American Red Cross
ASD – Anthrax Smoke Detector
ASPR- HHS Assistant Secretary for Preparedness and Response
BAR – BioWatch Actionable Result
BASIS – Biological Aerosol Sentry and Information System
BC – Betweenness Centrality
BDS – Biohazard Detection System
BIDS – Biological Integrated Detection System
BioALIRT – Bio-event Advanced Leading Indicator Recognition Technology
BioSTORM – Biological Spatio-Temporal Outbreak Reasoning Module
BSL – Biosafety Level
B-SAFER – Bio-Surveillance Analysis, Feedback, Evaluation and Response
CAP – Critical Analysis Period
CATWOE – Mnemonic device for Clients, Actors, Transformation, Worldview, Owner, Environmental Constraints
CDC – Center for Disease Control
CIA – Central Intelligence Agency
COG – (Metropolitan Washington) Council of Governments
COG BEPS – COG Bioterrorism and Emergency Planning Subcommittee
COG CAO – COG Chief Administrative Officer
COG HOC – COG Health Officials Committee
COG SPG – COG Senior Policy Group
CRI – Cities Readiness Initiative
DC DOH – DC Department of Health
DCHA – DC Hospital Association
DC HEPRA – Health Emergency Preparedness and Response Administration
DC HSEMA – Dc Homeland Security Emergency Management Agency
DHS – Department of Homeland Security
DHS FEMA – DHS Federal Emergency Management Agency
DHS NOC – DHS National Operations Center
DHS FEMA ONCRC – DHS FEMA Office of National Capital Region Coordination
DNI – Director of National Intelligence
DoC – Department of Commerce
DoC NOAA – DoC National Oceanic and Atmospheric Administration
DoD – Department of Defense
DoD NDMS FCC – DoD NDMS Federal Coordinating Center
DoE – Department of Energy
DoI – Department of the Interior
DoJ – Department of Justice

DoL – Department of Labor
DoS – Department of State
DoT – Department of Transportation
EMS – Emergency Medical Service
EOC – Emergency Operations Center
EOP – Emergency Operations Plan
EPA – Environmental Protection Agency
ESF – Emergency Support Function
ESSENCE – Electronic Surveillance System for the Early Notification of Community-based Epidemics
FBI – Federal Bureau of Investigation
FBI SIOC – FBI Strategic Information and Operations Center
FDA – Food and Drug Administration
FEMA – Federal Emergency Management Agency
GAO- Government Accountability Office
GSA – General Services Administration
GEOCOP – Geospatial Common Operating Picture
HAN – Health Alert Network
HHS – Department of Health and Human Services
HHS EMG – HHS Emergency Management Group
HHS IRCT – HHS Incident Response Coordination Team
HHS OSG – HHS Office of the Surgeon General
HHS SAMHSA – HHS Substance Abuse & Mental Health Services Administration
HHS SOC – HHS Secretary's Operations Center
HIS – Health Information System
HPHPG – Montgomery County, Maryland, Hospital, and Public Health Partnership Group
HSIN – Homeland Security Information Network
HSPD – Homeland Security Presidential Directive
IC – Incident Commander
ICE – Immigration and Customs Enforcement
ICS – Incident Command System
INFERNO – INtegrated Forecasts and EaRly eNteric Outbreak
IRCT- Incident Response Coordination Team
JAHOC – Joint All-Hazards Operations Center
JFO – Joint Field Office
JHU/APL – Johns Hopkins University Applied Physics Laboratory
JIC – Joint Information Center
JOC- Joint Operations Center
JTTF – Joint Terrorism Task Force
LRN – Laboratory Response Network
MACS- Multi Agency Coordination System
MOCEP – Montgomery County Emergency Preparedness Collaboration
MRC – Medical Reserve Corps
NCR – National Capital Region
NCPC – National Counterproliferation Center

NCTC – National Counterterrorism Center
NDMS – National Disaster Medical System
NDMS MIACG – NDMS Medical Interagency Coordination Group
NIC – NIMS Integration Center
NIH – National Institute of Health
NIMS – National Incident Management System
NIMS ICS – NIMS Incident Command System
NIMS MACS – NIMS Multiagency Coordination Systems
NNMC – National Naval Medical Center
NRCC – National Response Coordination Center
NRF – National Response Framework
NRP – National Response Plan
NRT- National Response Team
NVHA – Northern Virginia Hospital Alliance
NVRC – Northern Virginia Regional Commission
OAP – Office of the Attending Physician for Congress
OTC – Over-the-Counter
PCR – Polymerase Chain Reaction
PHS CC – U.S. Public Health Service Commissioned Corps
POD – Point of Distribution
RAND- Research and Development (Private Organization)
RODS – Real-time Outbreak and Disease Surveillance
RRCC – Regional Response Coordination Center
RSVP – Rapid Syndrome Validation Project
SETA – Systems Engineering and Technical Assistance
SNS – Strategic National Stockpile
SSAG – Stockpile Service Advance Group
START- National Consortium for the Study of Terrorism and Responses to Terrorism
USDA – U.S. Department of Agriculture
USPS – United States Postal Service
VA – Department of Veterans Affairs
VDH – Virginia Department of Health
VDH NVRT – Virginia Department of Health Northern Virginia Regional Team
VMI – Vendor Managed Inventory
vUSA – Virtual USA
WHO – World Health Organization
WMD – Weapon of Mass Destruction
WRTAC – Washington Regional Threat Analysis Center

1 Introduction

1.1 Team BIOCOUNTER

The Gemstone Program at the University of Maryland is a four year multidisciplinary research program for select honors students who are interested in pursuing and conducting research that aims to make an impact in the community regarding the interconnected fields of science, technology, and society.

Team BIOCOUNTER, or Bioweapon Inhibition and Organized Containment Operating Unit for the Negation of Terrorist Actors and Radicals, was formed by six students of varying academic focuses including Computer Science, Biology, Physics, Education, and Government and Politics under the mentorship of Dr. Jeffrey Herrmann. From the broad scope of public health and emergency preparedness, this multidisciplinary team formed in order to assemble and propose a research plan that delineated a research problem, hypothesis, and methodology. From conducting preliminary interviews, modeling an aerosolized anthrax attack, and compiling a literature review, Team BIOCOUNTER identified target issues and submitted a proposal for a four-year research project culminating in the publication and presentation of a thesis. Team BIOCOUNTER aims to examine and scrutinize the processes of detecting, investigating, and decision-making that would occur following an aerosolized anthrax attack in Washington, D.C. The response would require the cooperation of the entire National Capital Region (NCR), as the potential harm of an anthrax attack would affect the entire region. The ultimate objective of the research is to contribute to the safety of the NCR as well as the growing field of preparedness and emergency management research by using the NCR as a case study, with results including recommendations relevant to many other communities.

1.2 Threat of Anthrax

Bioterrorism has been receiving more attention as a possible national threat in the past decade, according to those in the public health community and researchers alike. Anthrax especially is a threat discussed repeatedly in scholarly literature. Aerosolized anthrax has been studied from a homeland security standpoint from its development as a biological weapon in Iraq in the 1980s (Ziliniskas, 1997) to its current threat as a potentially disastrous terrorist weapon (Inglesby et al., 2002). In the counterterrorism community, it has been said that anthrax presents the greatest biological warfare danger out of all other agents (Cieslak & Eitzen, 1999).

Anthrax is an acute disease caused by an infectious dose of *Bacillus anthracis*, a gram-positive bacterium capable of forming endospores (Cieslak & Eitzen, 1999). Although the disease is not contagious (Inglesby et al., 2002), the pathogens are very persistent in their spore form and can survive in a wide spectrum of climates and in the soil (Cieslak & Eitzen, 1999). The spores, ranging from 2 to 6 micrometers in diameter, are able to be inhaled into the human respiratory pathway, and cause infection when 8,000-10,000 spores are inhaled (Cieslak & Eitzen, 1999).

The incubation period for inhalational anthrax typically varies from 1 to 6 days with flu-like symptoms developing followed by a second stage of symptoms that may include cyanosis, dyspnea, edema, and hemorrhagic meningitis (Cieslak & Eitzen, 1999). If treatment begins after 48 hours after symptoms appear, death is as frequent as 95% of the cases (Cieslak & Eitzen, 1999). Those that have inhaled the spores must either take oral doxycycline or oral ciprofloxacin antibiotics even if the threat has not yet been verified. Thus, rapid treatment with prophylactic antibiotics is paramount for those have inhaled the aerosol. However, responders and physicians alike must have some acute awareness to conduct blood film tests to correctly diagnose the infection in the view of only its flu symptoms (Cieslak & Eitzen, 1999).

More background on the fatality and urgency of anthrax will be expounded in Chapter 2.1.

1.3 NCR Network

Officials and policy makers have created initiatives, protocols, and plans that are in place to prepare for a potential aerosolized anthrax attack. The NCR has an extensive network of such plans. This area, sometimes referred to as metropolitan Washington, D.C., includes Washington, D.C., northern Virginia (Arlington, Fairfax, Loudoun, and Prince William counties), and Maryland (Frederick, Montgomery, and Prince George's counties). This network of response therefore encompasses multiple geographic jurisdictions at the federal, state, and local levels of government.

Within each level of government, the planning process involves numerous federal agencies such as the Centers for Disease Control and Prevention (CDC) and the Federal Bureau of Investigation (FBI), as well as many local departments such as county emergency management agencies. In addition to government agencies and departments, other actors involved in the bioterrorism response include the Medical Reserve Corps (MRC) and the local hospitals in the region. Furthermore, officials within each organization have various roles that come with their own set of protocols or responsibilities that are separate from those of their colleagues. All of these actors and parties must collaborate and communicate with each other during the processes of detecting, investigating, and responding to an aerosolized anthrax attack in Washington, D.C.

The government agencies, private sector actors, and other parties involved in the response to an attack will hereafter be referred to as “actors.” Different actors have specific roles during subsequent stages of the response. From their roles and responsibilities, the actors will make their decisions and execute their response including information sharing, containment, prophylactic antibiotic distribution, resource allocation, and decontamination. We will elaborate such processes, initiatives, protocols, and guidelines in more detail in Chapter 2.

1.4 The Problem

Because aerosolized anthrax has such a high mortality rate in the absence of immediate treatment, actors need to carry out their responsibilities quickly and efficiently. However, with so many actors involved in such an effort, it can be overwhelming for these joint operations to proceed without discrepancies. As no large-scale aerosolized anthrax attack has ever occurred, case studies do not exist to appreciate or scrutinize the processes during such a large-scale scenario.

As shown in Figure 1.4, the response can be split into several distinct components. First, the anthrax is released and people are exposed to the pathogen. Next, the attack is detected and confirmed. Once detected, information is gathered in a collaborative investigative effort before the actors involved are able to decide on the appropriate response. The detection, investigation, and decision-making phases can be grouped together into the Critical Analysis Period (CAP). Once the actors decide on how to respond to the attack, it will take more time before the plan can be fully implemented. For example, it should take a maximum of 48 hours to set up a point of distribution (POD) for prophylaxis dispensing according to the Cities Readiness Initiative (CRI, 2004). The delay between deciding on the solution and implementing the solution has been dubbed the Response Delay. Finally, the response is executed in what has been labeled the Solution.

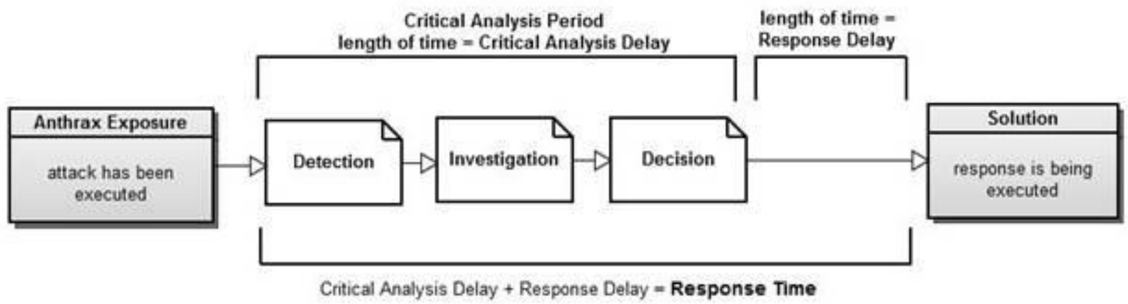


Figure 1.4 – Critical Analysis Period

We intend to limit the length of the CAP and the Response Delay, as well as rearrange the current system so as to make the path to the Solution more methodical and less ambiguous. The state of the CAP and Response Delay is something that was researched further in the literature review.

There are some existing studies and reviews that indicate an imperfect system. These studies largely show failures to communicate, failures of leadership, and a general sense of unpreparedness, all three of which could lead to needlessly delayed CAP.

In 2010, the Center for Biosecurity at the University of Pittsburgh held a conference entitled *The State of Biopreparedness: Lessons from Leaders, Proposals for Progress*. The conference's goals were to analyze and review the multiple advances made in biosecurity from 2001 to 2010 and to develop a growing understanding of future directions for improvement. The speakers, including major health officials and members of the Cabinet, discussed a range of topics, from new technologies and surveillance to improving medical response and situational understanding.

One such speaker, Bob Graham, former governor and senator from Florida, served as chairman of the WMD Commission. He noted many similarities in the response to oil spills and the outlook on the financial industry (Graham, 2010). Notably, he spoke of the “diminution of threat,” which includes the dismissal of warning signals, something that Graham has taken attention to and opposes. His commission found that terrorists have been quickly adapting to any security measures taken, that terrorists would likely use a WMD before the year 2013, and that this weapon would most likely be biological instead of nuclear. The Commission’s non-profit successor, the WMD Policy Center, gives an annual report card on WMD interdiction for the United States. In 2010, that report card administered failing grades of “F” in three categories under “national security,” one of which included “prepared and quick response to bioterrorism” (Graham & Talent, 2010). The Center referred to a failure to “recognize, respond, and recover from a biological attack.”

Another study, by the Research and Development (RAND) Defense Institute, investigated and analyzed the performance of the Department of Defense (DoD) in responding to three anthrax-related incidents (Kelly et al., 2006). Using primary documents and interviews, the study thoroughly scrutinized the system in place, the way that the system should be designed, and recommended specific improvements. The results revealed uncertainty, poor communication and coordination, and noncompliance with the framework guidelines of the National Incident Management System (NIMS).

In 2005, the Department of Defense commissioned the RAND Defense Institute to review responses to possible anthrax-related incidents at three of the department's mail facilities, namely those at the Pentagon, the TRICARE Management Agency's Skyline in Fairfax, Virginia, and the Defense Intelligence Agency's remote delivery facility in Washington, D.C. These responses were compared to existing plans and already established guidelines. The study noted that response at the facilities was conducted separately, leading to further problems (Kelly et al., 2006). Most importantly, each separate response was conducted without compliance to then-existing NRP and NIMS guidelines, which led to improvised responses from DoD officials and poor inter-agency coordination. This showed that the DoD had failed to adopt the systems fully, and the authors recommended that full compliance be completed in the case of a real attack. However, although there were problems with the DoD in NRP/NIMS compliance, the roles themselves were not clearly defined in the plans at the time either.

The Government Accountability Office (GAO) sent agents to investigate the five Biosafety Level 4 (BSL-4) laboratories in the United States. Three of the five labs were considered to be in good standing, meeting thirteen, fourteen, and fifteen of the fifteen security categories, respectively. The two low-scoring BSL-4 labs met only three and four, respectively, of the fifteen categories. Nevertheless, both of these labs met the standards of the Division of Select Agents and Toxins of the CDC (Graham et al., 2008). The Homeland Security Council also stated that, in a hypothetical aerosolized anthrax attack, initial cases would not arrive in emergency rooms until thirty-six hours after the release, with the number of people with symptoms increasing quickly over time (Ibid.). An aerosolized anthrax attack released by truck in an urban city is estimated to result in 328,848 exposures, 13,208 untreated fatalities, and 13,342 total casualties (Ibid.). In response to the many findings with regards to biosecurity, the commission called for the following action:

> "The next administration should, as a priority, work with a consortium of state and local governments to develop a publicly available checklist of actions each level of government should take to prevent or ameliorate the consequences of WMD terrorism. Such a checklist could be used by citizens to hold their governments accountable for action or inaction (Graham et al., 2008, p. 109)."

The report covers a wide range of subtopics from international bioweapons prevention to reform of American governmental oversight of biosecurity. The thirteen recommendations address both biological and nuclear risks and security issues.

In accordance to the above recommended action, the public has made assessments of the United States' emergency preparedness. *The New York Times Magazine* reported as recent as October, 2011, discrepancies in ideology between the Department of Homeland Security (DHS) and the National Institutes of Health (NIH) (Hylton, 2011, p. 9). The article also states that there had been a single biodefense director in the 1990s and early 2000s with the purpose of coordinating government response, but this position has since been replaced with four officials with "partial responsibility" (Ibid.). A Rutgers University professor familiar with biosecurity noted that safety is based in part on peoples' personal feelings, explaining as an example that people felt more secure about airplane travel before September 11th than afterward. Additionally, actors may be in conflict because of role interests, in which each single actor wants to play the role of the "hero" (Ibid.).

Notably, a project by Dr. Caron Chess, Director of Environmental Communication at Rutgers University, offered further information on risk communication in a crisis. The study's methodology heavily relied on interviews of health officials and local responders and analyzed the organizational aspects of the response to the 2001 Amerithrax crisis (Chess & Clarke, 2007). The project found that the actors involved in the response faced organizational uncertainties such as confusion over the distribution of authority and responsibility. Organizational networks, including local and informal networks, were found to be crucial to the operations of response. Prioritization of communication (e.g. ensuring that the most important recipients receive the most important information through the most important channels) was found to be a major problem. Time delays occurred in response to the crisis from factors such as hesitation to sharing information with certain partner agencies in addition to the confusion regarding chain of command. The study also addressed the relationship between actors, whom Dr. Chess calls "elites," in response and panic, including elites fearing and causing panic, and even the panic of elites themselves (Ibid.).

Elaine Vaughan, at the University of California, Irvine, has studied risk communication with certain ethnic and social classes in the United States, especially lower-income minority groups. Factors of note included distrust of government within these communities, ill perceived subtext in official statements and announcements attempting to assuage any panic, and delay of communication to these communities. The dichotomy between false positives and false negatives was also an interesting topic discussed, with the study concluding that false negatives were far more detrimental to risk communication and public perception of responder agencies than false positives (Vaughan, 2009).

An additional study examining risk communication in New Jersey revealed a list of discrepancies and cases of ambiguity in times of public health emergencies. Interviews with professionals and officials of involved agencies identified frustration regarding lack of communication, coordination, and at times, trust, as the foremost causes of disorganization in a variety of cases. Medical practitioners even cited politics as an aggravating pressure on their decision-making for dispensing prophylaxis. The study revealed that sharing information between agencies might cause misconstrued communication, which has led to public confusion and prolonged response times. The study called for more systematic research to be done regarding this interagency uncertainty (Chess & Clarke, 2007).

In the NCR, risk communication and response can potentially be more complex than what was examined in New Jersey. With the incorporation of various jurisdictions as well as the centralization of federal agencies in the NCR, roles and guidelines must be clearly defined with correct boundaries and responsibilities. As a result, the system should be studied as a “mess”, or an interconnected problem across a complicated society that cannot be distinguished easily through immediate analysis, rather than as a simple response plan.

The summation of these studies reveals that various factors lead to an ambiguity that might occur following an aerosolized anthrax attack, between the detection of the pathogen and the execution of a response. Such factors responsible for ambiguity include the processes of inter-agency coordination (Bush, 2004) and the proper determination of a course of action according to one of our public health contact. This resulting ambiguity would increase the response time in the event of an aerosolized anthrax attack, leading to increased deaths as a result of the attack.

1.5 Objectives

The research questions that guided this study were: (1) what are the inefficiencies and disorganization within the CAP after an aerosolized anthrax attack, and (2) what framework can be developed and implemented to improve the overall response system so as to reduce the overall response time of the actors?

Reducing the response time is critical to minimizing the number of casualties. As described in Chapter 1.2, anthrax has a very high mortality rate for those who are exposed but do not receive prophylaxis. However, the population is unable to receive prophylaxis until much of the response system is completed (see Figure 1.4). Another effect to consider are hospitalization surges that could delay patients from immediate treatment if the hospitals are over-capacitated. Hupert et al. used computer simulations to model the number of potential hospitalizations based on estimated response time following a release of anthrax. As described in its results, each additional hour of the response time increases the number of casualties significantly (Ibid.).

Our research began with the acquisition of knowledge on all relevant topics. We then investigated the factors could the ambiguity of the procedures that follow an aerosolized anthrax attack, and subsequently developed recommendations for relevant agencies such as the CDC and DHS to improve the system and thus decrease the response time following an attack. Although none of the research performed here involved classified information, we have chosen to omit some of our results and recommendations for security and classified purposes. The results are included in the conceptual models found in Chapter 5. The decrease in response time will attribute to a decrease in the number of potential contacts and casualties following an attack. Our methodology will be further explained in Chapter 3.

1.6 Method Framework

We implemented Soft Systems Methodology (SSM) as the basis of our methodology. SSM is primarily implemented to systematically evaluate complex systems and messes (Checkland, 2000). SSM will be discussed in detail in Chapter 3.

The first component of SSM involves acquiring information about the problem. This was achieved by conducting an extensive literature review, as well as interviews of over 20 individuals representing the actors involved with planning and response to an attack.

Next, we created visual representations of the problem. To do this, the flow of information among the actors was represented in an adjacency matrix, and the results were displayed using the program NodeXL. The graph shows the complexity of the system while also revealing patterns and connections. Using this graph, as well as information obtained from the literature review and interviews, we developed rich pictures. The purpose of rich pictures is to visually display our understanding of the problem so we could then determine if it agrees with the perspectives of the officials involved in the response (Checkland, 2000).

Our next step was to create models of interaction, which showed the sequence and timing of events that should occur in an idealized response to an anthrax attack. This was modeled using the Critical Path Method (CPM), which allowed us to determine the path of a response from the release of anthrax to the dispensing of prophylaxis.

For the models of interaction, we wanted to a sample, computerized anthrax attack on which we could base the response. Although there are descriptions of aerosolized anthrax simulations, no simulation was found to give an hour-by-hour map of the location of people who would likely exhibit symptoms of anthrax. Consequently, we designed our own simulations. For our sample anthrax attack, we modeled the dispersion of the anthrax using the NOAA HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) program, and based on this dispersion, computed where and when people would likely exhibit symptoms. The model that we used for our simulations is described in Section 3.9.2. Our methodology will be detailed in Chapter 3.

1.7 Contributions to Community and Research

This research will have a direct contribution to the community by providing recommendations that would reduce the response time to an aerosolized anthrax attack. This, in turn, would save lives if an attack were to occur. In addition to the recommendations, the rich pictures and models of interaction we have constructed are useful pieces of information that provide new ways for understanding the structure and coordination of a response.

Although the focus of this thesis is on the response to an anthrax attack in Washington, D.C., the methodology used could be adapted for analyzing a wide range of emergency response situations. Some recommendations are also directly applicable to similar threats in the NCR, such as other biological outbreaks.

The anthrax dispersion simulation provides its own contributions to the literature, as well as having its own limitations. These will be further discussed in Chapter 4.4.

2 Literature Review

2.1 Anthrax Background

Before the Amerithrax case of 2001, the most recent American incident involving inhalational anthrax was in 1957. That year, five employees at a large goat-hair processing mill in Manchester, New Hampshire, exhibited anthrax-related symptoms over a ten-week period, resulting in four fatalities (Brachman et al., 1966). Although anthrax posed a legitimate threat in the wool and animal product industries during the early 1900s, a combination of improved animal breeding, better processing of products, and the development of anthrax vaccines as early as the 1950s mitigated adverse effects (Sternbach, 2003). In the decades following the 1957 incident, military researchers learned how to weaponize anthrax and release it as a tactic of biological warfare.

Previous terrorist use of anthrax is scant but well documented. In 1981, a terrorist group in the United Kingdom, known only by the name of “Dark Harvest,” collected samples of the still contaminated soil and distributed them, first to the grounds of the Chemical Defence Establishment in Wiltshire, England, and then to a meeting of the Conservative Party. Dark Harvest’s purpose was to bring attention to the germ and chemical warfare tests undertaken by the British Army. Although no lives were lost and the plot was ultimately a failure (especially with the lack of anthrax spores in the second container), the attacks nevertheless spurred the British government to begin efforts to decontaminate the island.

The use of anthrax as a biological weapon was again found to be a feasible tactic when an investigation of Iraq’s bio-weapons program in the mid-1990s showed that the Iraqi military was able to develop and test anthrax as such. The weapon was comprised of four components: a payload (a chemical agent), a munition (a container for the virulent payload), a delivery system (an aircraft or missile), and a dispersal mechanism (a force or machine that weaponizes the agent as an aerosol spore for release on a target population) (Zilinskas, 1997). Scholars have stressed that a well-funded terrorist group could procure these means of bioterrorism or hire the expertise needed to develop such tools (Inglesby et al., 2002).

Anthrax spores are resistant to desiccation, ultraviolet light, heat, and various disinfectants (Cieslak & Eitzen, 1999). Spores can persist in nutrient-rich soil for decades until contact is made with a living host (Hugh-Jones & Blackburn, 2009). Interestingly, it is noted that antibiotics only successfully kill the anthrax bacteria, and leave behind the fatal toxin left by the bacteria (Croft et al., 2005, p. 693). An aerosolized dispersal of this agent along a 100-km line under optimal climate conditions could cause a 50% lethality rate throughout a 160 km span of land.

In the 1979 outbreak in Sverdlovsk, a Soviet military compound accidently released anthrax spores into the outside environment, causing over 66 deaths (Meselson et al., 1994). The majority of the victims resided in the narrow path directed south from the military compound, towards Sverdlovk's border. This information allowed officials to identify the spread's origin. Government officials reported livestock contamination with 96 cases of human infection with initial symptoms arising from April 4 to May 18. In 1990, interviewed Sverdlovsk officials said they had been developing an improved vaccine but were unaware of the escape of anthrax pathogens. The report itself gives tabulated statistics of the infected persons, from gender to survivors and other information about the victims. The statistics include mention of the symptoms reported:

fever, dyspnea, cough, headache, vomiting, chills, weakness, and abdominal and chest pain. These are common symptoms associated with anthrax. Also included are tables showing number of deaths versus time (Meselson et al., 1994).

In addition to physical harm, an aerosolized anthrax attack would produce psychological and social effects (Wyatt, 2002), such as population disorganization and unsustainable family incomes due to forced leave. (Hunter, 2007). Hultgren shows that, due to these factors, even in a scenario in which it takes three days after detection to treat with prophylaxis and 90% compliance, as many as 10% of the affected population could die three weeks after exposure (2007). If detection occurs at as long as 15 days after exposure, then even with the same timeliness and compliance, nearly 90% of the affected population could die within three weeks after exposure (Ibid.). Researchers believe that a 100-kilogram release of anthrax in Washington, D.C., could kill as many as 3 million people (Yung et al., 2007). All of these aspects contribute to anthrax serving as a likely agent for bioterrorism.

The most recent anthrax incident in the United States was in March, 2005, at the Pentagon. A routine test detected trace amounts of anthrax spores in the building, the same day that an air-handling equipment alarm went off in a DoD office in a privately owned building complex in Fairfax County, Virginia. The Northern Virginia Regional Team (NVRT) provided personnel, determined prophylaxis logistics, prepared reports, and maintained contact with the NCR as well as with the Virginia Department of Health (VDH) and CDC (Stoto & Morse, 2008). In both the Amerithrax and the 2005 cases, the NCR required a response. If a large-scale anthrax attack occurs in the region, all relevant agencies must have a sound set of responsibilities and efficient methods for achieving them.

Studies of weaponized anthrax have been conducted by the public, academia, and government, and have ranged from assessments to simulations. Among the most significant of these assessments is *World at Risk: A Report of the Commission on the Prevention of WMD Proliferation and Terrorism*, published in December, 2008, under the guidance of former Senators Bob Graham and Jim Talent. The report included information compiled from interviews with over 250 government officials, eight major commission meetings, and one public hearing (Graham et al., 2008). This report asserted that, without proper global action, terrorists could execute an attack with a weapon of mass destruction (WMD) by the end of 2013. In addition, biological weapons were a more likely threat than nuclear weapons and the margin of safety was shrinking rather than growing (Ibid.). Although the Biological Weapons Convention of 1972 prohibited development, production, and acquisition of biological weapons, violations and a lack of an international strategy have negated the original intentions (Ibid.). The report went so far as to explicitly state, "The President should create a more efficient and effective policy coordination structure by designating a White House principal advisor for WMD proliferation and terrorism and restructuring the National Security Council and Homeland Security Council" (Recommendation 8, Graham et al., 2008).

Certain academic studies have also evaluated the protocols of detection, investigation, decision-making, and response. Nan D. Hunter, at Georgetown University, assessed three hypothetical approaches to governance of public health law: dominant state authority, public-private model for administrative governance, and governmentality theory (Hunter, 2007). Hunter's analysis concerned the legal obligations of employers and economic recommendations for individuals in the event of a bioterorrism incident. The study suggested that employers should revise their policy on employees' leave of absence (Hunter, 2007).

Researchers have also conducted simulations of hypothetical aerosolized anthrax attacks in order to understand the logistics of the response. With the knowledge that a one-kilogram release of anthrax could result in 100,000 deaths and that as many as 10,000 people could die as a result of delayed prophylaxis, Croft et. al (2005) conducted simulations to analyze the stages of symptoms and treatment. The simulation accounted for amount of release, wind, release height, breathing rate, zone population, biosensors, symptoms, and a wide variety of other parameters. The simulation also accounted for the incubation, prodromal, and fulminant stages of anthrax among patients. The study analyzed the effects of overwhelmed hospitals and delays in response. Such observations provide insight on what potential problems could occur in an actual response.

2.2 Current Policies

2.2.1 Background on Response Protocols

The National Response Framework (NRF), which was created and published in 2008, is the culmination and reorganization of former response plans, especially the National Response Plan (NRP) formulated in the years following the September 11, 2001, attacks. The NRF was specifically designed to be an all-hazards approach to any disaster, from naturally occurring disasters to large-scale terrorist attacks (NRF, 2008). The document divides and explains the work of preparation and response from all levels of government, federal, state, and local, as well as appropriate actions to be undertaken by non-governmental actors and private sector stakeholders. The document outlines the provisions of the NIMS as well as the Emergency Support Functions (ESFs).

Beginning in Fiscal Year 2005, in accordance to Homeland Security Presidential Directive #5 (HSPD-5), NIMS became a required set of protocols for local, state, and federal agencies involved in emergency preparedness in order to receive federal funding (HSEMA, 2011). NIMS attempts to standardize training, awareness, communication, and coordination among agencies throughout different levels of government, and across multiple jurisdictions. Washington, D.C., established a NIMS Advisory Group in accordance with Homeland Security Presidential Directive #8 (HSPD-8) in order to implement NIMS in an orderly and feasible fashion (HSEMA, 2011). NIMS can be divided into the Incident Command System (ICS), Multi-Agency Coordination Systems (MACS), and Public Information Systems. The ICS has already been developed to assign responsibilities to relevant agencies during any natural disaster or emergency. MACS involves the proper coordination and use of facilities, equipment, and people in order to best respond to an emergency, while the Public Information Systems addresses communication protocols (HSEMA, 2011). Both HSPD-5 and HSPD-8 were issued in 2003 and began this process of attempting to standardize multi-jurisdictional emergency preparedness and response.

The ICS, one of the guiding set of protocols that became a part of NIMS, was first developed in the 1970s in response to fires in urban California (FEMA, 2008). This system attempts to designate specific roles to local, tribal, state, and federal governments in order to coordinate an appropriate response. The ICS addresses standardization, command, planning/organizational structure, facilities and resources, communications/information management, and professionalism. The system has established a specific organization of actors in the following format: incident commander or unified command, command staff, operation section, planning section, logistics section, and finance/administration section. Some incidents may require a unified command in order to address the full complexity. In the event of bioterrorism, both public health and law enforcement would need to contribute their respective expertise.

Attempts at coordinating actors have led to quite a few more actors specifically organized for coordination. The National Response Coordinator Center (NRCC) is delegated within the Federal Emergency Response Management Agency (FEMA) and acts to initially implement emergency operations and carry out communication channels between DHS and emergency response teams. The Regional Response Coordination Center (RRCC) is a more local arm of FEMA that works with the NRCC to initiate emergency protocols in specific areas. Joint Field Offices (JFO) are mobilized coordination actors that take over much of the roles of the RRCC and NRCC following an emergency. The Joint Operations Center (JOC) is a homeland security and defense multi-agency command post that helps to coordinate actors in emergencies. The specific JOC, the Joint Force Headquarter National Capital Region (JFHQ-NCR), is a military entity not part of the DC government and is part of the Military District of Washington for the US Army, which is now a component of the US Northern Command. The Joint All-Hazards Operation Center is a coordination post within the DC government that helps to spread communication among government actors, which becomes an Emergency Operations Center (EOC) when mobilized.

One of the most fruitful documents in specifically describing the federal government's response to an aerosolized anthrax attack is the Aerosolized Anthrax Concept of Operations, or ConOps (PHE, 2012). This document was sponsored by the DHS Office of the Assistant Secretary for Preparedness and Response and offers a brief yet telling list of actions that would occur in the event of an attack. The ConOps begins with four "trigger events": credible intelligence of a plan to conduct a biological attack using aerosolized anthrax, notification of a Biowatch Actionable Result (BAR), confirmed cases of inhalation anthrax, and a decision to demobilize. The last scenario, decision to demobilize, succinctly describes the requirements for demobilization subsequent to an alleged attack. The ConOps acted as a framework from which we could trace the path of response, and also encouraged us to analyze an attack in multiple scenarios.

The National Contingency Plan (NCP), fully known as the National Oil and Hazardous Substances Pollution Contingency Plan, is the national plan for oil spills and hazardous material release. It is coordinated by the Environmental Protection Agency (EPA), the National Response Team (NRT), and FEMA. The NCP includes biological and chemical hazards in their list of hazardous materials. The plan also includes guidelines for testing water and air for pollutants and hazards and for decontamination. Although it was written primarily to provide contingencies for pollution, especially on a massive scale, the plan can be applied to an aerosolized anthrax attack, especially in consideration of decontamination.

The ESFs were created in line with NIMS in order to provide guidelines for the allocation of resources and the coordination of multiple related federal agencies. Each

ESF specifies one or more primary actors that provide the majority of staff, support, and resources. Each one also has multiple support agencies that provide additional support and improve response. There are fifteen ESFs and each one is assigned to a specific area of expertise. For example, there are individual ESFs for Communications, Firefighting, Public Health and Medical Services, and Long-Term Community Recovery. Activated ESFs authorize actions by the relevant agencies so that they can address all aspects of the response.

ESF #8 in particular discusses Public Health and Medical Services. It is the most directly related ESF to our scenario. In agreement with unified command, the Department of Health and Human Services (HHS) is the lead federal agency of this function. The HHS Emergency Medical Group (EMG) increases the number of people on duty when the NRCC activates the function, and in collaboration with the DHS, sends appropriate personnel to determine the specific needs of the affected population. As the HHS increases its scrutiny of surveillance and investigation of bioterrorism, it also instructs personnel such as the DoD, VA, and MRC to work on scene as responders. In addition to the SNS, the function grants the authority to request additional supplies from the DoD and VA. If evacuation is necessary as a result of symptoms or other appropriate conditions, this function can instruct the DoD, VA, and FEMA to transport patients. All of these actions require standardization across actors. The HHS EMG, via the HHS Secretary's Operations Center (SOC), communicates with the National Operations Center (NOC). All necessary information sharing occurs between the relevant actors and the NRCC, RRCC, or JFO. JIC coordinates information sharing with the general public upon approval from the HHS.

The Office of the Assistant Secretary for Preparedness and Response (ASPR), under the auspices of HHS, released their Online Performance index for Fiscal Year 2012. The purpose of this document is to gauge the performance of the ASPR in multiple fields, from ensuring that public health and responder officials are capable and strengthening the healthcare infrastructure to measuring and relating with international efforts. The document also examined the office's budgeting and logistical issues. In looking at the agency's performance, the report carefully examined certain programs instituted to aid the office in its goals, e.g., the Hospital Preparedness Program and the Medical Countermeasure program. Of note is Measure 2.4.4.A, which examined the medical countermeasures for anthrax. In past years, ASPR has worked with the Biomedical Advanced Research and Development Authority to provide contracts to support the development of anthrax vaccines. However, in recent years, the organization has either not reported if its target goals have been met or failed to meet its goals. Nevertheless, HHS increased its budget on emergency preparedness and response by over 46% from FY 2011 to FY 2012 (Holland et al., 2012).

The federal government has stressed the need to prevent bioterrorist attacks before technological surveillance is needed. The government has established coordination and an effective basis to impede shipments and delivery systems of biological weapons among suspicious actors that are in line with the United Nations Security Council (DoS, 2003). There is a new stress on rapid communication and global coordination. Ensured security may require allowing other countries to investigate vessels and searching oceanic regions (DoS, 2003). The stress on searching foreign imports comes from the possibility of anthrax leaving a potentially natural environment to a region in the country where it can cause casualties. These concerns have led to the creation of the Proliferation Security Initiative (PSI), an international effort to end weapons trafficking. The principles of the PSI rely on interdiction, halting the trade of weapons of mass destruction in general, in line with domestic authorities and international law (DoS, 2003). The PSI calls on all nations involved to take effective measures against WMD trade, to adopt streamlined procedures for communication, to strengthen national authorities in training for these objectives, and to take a proactive approach in interdiction. The PSI shows that the need and concern for ease of communication and coordination of response are also emphasized on the international level.

The District Response Plan (DRP) incorporates NIMS within the NCR. The plan outlines specific roles for NCR jurisdictions related to operations, EOCs, consequence management team structure, activation of the D.C. National Guard, federal partners, and recovery operations (Gray & West, 2008). The mayor of Washington, D.C., has a specific set of responsibilities pertaining to funds and orders, as well as communication with other relevant officials on multiple levels of government. The consequence management team (CMT) contains officials associated with operations authorized by all of the ESFs as well as the mayor and the HSEMA, and it operates the EOCs. The DRP, NIMS, and NRF outline a number of ideal responsibilities for tribal, local, state, and federal government agencies in the event of a large-scale emergency.

Future measurements of NIMS compliance and self-assessments will show whether identified discrepancies are addressed. In 2006, the District of Columbia Emergency Management Agency (DCEMA) developed an implementation plan for NIMS compliance in accordance with Homeland Security Presidential Directive 5

(HSPD-5) The plan ensured that responsibilities were explained thoroughly and delineated clearly, especially the roles of the Mayor and the directors of different agencies. Also, in line with NIMS compliance, there are also very specific instructions regarding points of contact and identification of key personnel. The majority of the document explains the specifics of implementation. It first describes the seven phases of implementation, from initial recognition to institutionalization of the Incident Command System (DCEMA, 2006). Furthermore, the plan has a set timetable for NIMS adoption. Training of staff, mentioned in Phase Two of implementation, is also key to the plan, including identification of required training courses, which include introductions to ICS, NIMS, and the then-existent NRP. The plan goes on to discuss adoption self-assessment using NIMCAST and documentation of compliance. Even further, the plan describes the modification of the existing plans to fit NIMS requirements, including testing and refinement. Resource management, which the plan pairs with certification and credentialing of D.C. employees and equipment, and NIMS Integration Center standards, which are in line with the Homeland Security Exercise and Evaluation Program (HSEEP), are the final topics discussed. The document provides a loose understanding of current procedures of implementation and a better look into primary adoption of NIMS guidelines in the past.

Actors within the Washington, D.C. government include the Health Emergency Preparedness and Response Agency (HEPRA) within the DC Department of Health (DCDOH) and the Homeland Security Management Agency (HSEMA). The primary purpose of HEPRA is to survey for, protect against, and act against biological threats, especially bioterrorism. The primary purpose of HSEMA is to manage any situation, under the Mayor of D.C., that relates to homeland security, by keeping in touch with all relevant actors and the public. Other regional government actors include the FBI Field Office and FBI WMD Coordinator and the RRCC.

2.2.2 Surveillance and Detection

The United States first implemented the concept of surveillance to protect public health in 1878 to monitor cholera, smallpox, plague, and yellow fever (Fedorowicz & Gogan, 2009). The means of detecting anthrax can be divided into two categories: technological and syndromic. Technological surveillance uses detection systems and central computers to identify bioterrorist attacks, whereas syndromic surveillance involves analysis of health patients' symptoms by doctors and epidemiologists to determine if there is an instance of bioterrorism. The United States government has developed methods for both forms of surveillance.

The primary technological surveillance system, known as BioWatch, received initial funding in spring of 2003 (Fedorowicz & Gogan, 2009). BioWatch is essentially a network of air filters, placed throughout large cities. The process begins with an airborne pathogen landing on filters mounted on EPA air quality monitoring stations. The filters are collected every 24 hours and analyzed at laboratories associated with the national Laboratory Response Network for Bioterrorism (LRN). The CDC initially oversaw the analysis of the filters, while local jurisdictions and the FBI determine the proper solution (Shea & Lister, 2003). In recent years, however, the labs have had virtually full jurisdiction over the analysis. Early detection and a short CAP allow for an early warning, in which simple protocols such as closing windows and remaining relatively inactive can prevent exposure to a large-scale attack (Wyatt, 2002). Proper analysis of

BioWatch requires strong understanding of wind patterns as well as strategic location of detectors. An aerosol cloud appears only when released, has heterogeneous concentration, and is susceptible to further distribution variability due to the high altitude of release (Wyatt, 2002). Additionally, BioWatch's sensitivity must be taken into account, as some pathogens are naturally present in the atmosphere at background levels in certain parts of the United States. The Biological Aerosol Sentry and Information System (BASIS) uses the same concept of filters that automatically rotate on an hourly basis, and the used filters are manually removed for testing Although the process of removing the filters and analyzing the agents requires manual labor, BASIS has less than 0.005% false positives per filter measurement (Shea & Lister, 2003).

Currently, there are discussions and attempts to improve technological surveillance. The DHS has announced that BioWatch must be a quicker, autonomous system that can reduce the analysis period from between ten and thirty-four hours down to between four and six hours (Garza, 2009). The LA Times reported throughout 2012 in several articles that BioWatch is unreliable due to false alarms, delays, and even a lack of recognition of actual pathogens (Williams, 2012). The federal government has allotted funding in recent years for Generation 3 BioWatch, which will be fully autonomous with analysis capabilities three to six times per day, detect smaller attacks than the original BioWatch program, and have a per unit operational cost of less than 25% of the current system (Hultgren, 2007). However, in late 2012, Generation 3 BioWatch was put on hold due to lack of progress. Currently, options are being explored again for continuing research for Generation 3 (Perera, 2013).

Other technologies independent of BioWatch have been tested as well. The anthrax smoke detector (ASD) is an automated front-end monitor that uses air samples and low-cost chemical tests that reduce security costs by an estimated two orders of magnitude (Yung et al., 2007). Simulated anthrax attacks revealed that the ASD could detect as few as sixteen spores per liter of air within a 250 liter sample (Yung et al., 2007). Similarly, the autonomous pathogen detection system (APDS) has the capacity to test 3000 liters per minute, and the samples it tests are archived (Hindson et al., 2004). The APDS can run initial tests of samples for anywhere from thirty and sixty minutes, and if the results are positive, it can indicate the need for a response. Additional testing for up to eighty minutes can determine the need for a more involved response (Hindson et al., 2004). The system has undergone tests in a Washington, D.C., subway and an Albuquerque, New Mexico, airport, and the DHS has conducted field operations and overseen commercialization (Hindson et al., 2004). In addition to these varying forms of technological surveillance, a vast number of syndromic surveillance systems have been developed.

Although many different technologies have been developed to detect anthrax and share information, there has not been a comprehensive review of which ones are most effective. Part of the problem is making the connection between the clinicians and public health officials' informational needs and the capabilities of the existing technologies (Bravata et al., 2004). In an attempt to provide some form of evaluation, Bravata and colleagues evaluated 341 reports of 217 existing information technologies and decision support systems. The researchers developed evaluation criteria by reviewing the 2001 anthrax cases, TOPOFF and the Dark Winter bioterrorism preparedness exercises, the

1993 *Cryptosporidium parvum* outbreak in Milwaukee, Wisconsin, the 1999 West Nile Virus outbreak in New York City, and a number of clinical guidelines, emergency preparedness standards, and security protocols. The study also identified roles for clinicians and public health officials as well as identified the stages of decision-making. Clinicians must correctly diagnose the biothreat agent, rapidly manage the care of potentially exposed patients, take precautions to prevent additional spread, and report both suspicions and confirmations of cases to public health officials on all levels. Public health officials must gather and analyze surveillance data, when and how to perform an epidemiological investigation, determine logistics of necessary outbreak control measures, and communicate with first responders, clinicians, other public health officials, and the general public. Decision-making could be identified in three stages: clinicians make diagnostic, management, prevention, and reporting decisions of initial cases; public health officials make surveillance, investigative, control, and communication decisions regarding initial cases; and clinicians determine the course of action for additional cases.

In 2004, DHS adopted a detailed defense program in compliance with Homeland Security Presidential Directive #10 (HSPD-10, 2004). With regards to threat awareness, biological warfare related intelligence, assessments, and anticipation of future threats are kept up-to-date and the department pays special attention to time and accuracy in order to help all sectors of society be best prepared (Ibid.). Prevention and protection are rooted in the secrecy regarding biological agents and how to use them. Additionally, detection technologies and decontamination methods require constant updating. Surveillance and detection plans on a national level will allow for some form of uniformity to prevent social disruption, but it must be balanced with local, state, and international plans

(HSPD-10, 2004). The early-warning system must track the dynamics of the aerosol cloud, classify initial agents, and provide a time frame for protective action (Wyatt, 2002). Analysis extends to finding the perpetrator, and the response involves coordinating between the NRF and local and state plans (HSPD-10, 2004). DHS would oversee transportation and law enforcement while HHS would run the response and both departments would work alongside with the EPA, the Attorney General, and the Secretaries of Defense, Agriculture, and Labor to devise the best plan for decontamination (Ibid.). Directives #5, #8, and #10 have influenced and in some cases initiated all of the preceding plans.

Syndromic surveillance detects bioterrorist attacks and natural disease outbreaks through the local and state health departments' analyses of hospital reports and pharmaceutical purchases. The CAP starts on the local (county) level, and, if symptom patterns occur among different communities, the state health department investigates on a broader scale. The system of the "observant doctor" takes effect when a patient exhibits odd symptoms or the doctor notices an unusual increase in a certain symptom. According to our public health contact, physicians can alert the CDC within a day. Epidemiologists analyze the incoming cases and look for patterns. Over the course of anthrax's varying incubation period (ranging from 1 day to 17 days), the health department can conclude whether or not an attack has occurred.

Two specific surveillance efforts sparked the possibility for improved monitoring. In 1999, both the University of Pittsburgh Medical Center and Harvard Medical School developed independent syndromic surveillance systems based primarily on patient chief complaint data (Fedorowicz & Gogan, 2009). Such data allowed the analysts to take symptoms and associate them with anthrax before a doctor's confirmation.

The federal government's BioSense program relates patients' symptoms to a set of syndrome groups that help epidemiologists and other health officials identify clusters of systems (Fedorowicz & Gogan, 2009). On a federal level, BioSense integrates the Department of Defense, Veterans Affairs facilities, and hospitals throughout multiple states (10 as of 2008) to quickly and accurately identify a bioterrorist attack (Ibid.). The program has since changed to detect natural outbreaks of diseases. In 2005, the CDC established direct connections with hospitals in order to receive cycles of data on a 15 to 20 minute basis (Rolka & O'Connor, 2011). This current system works independently of the BioWatch program.

The Real-time Outbreak and Disease Surveillance (RODS) is a high-tech approach to syndromic surveillance. As of 2003, RODS uses a computerized public health surveillance system in accordance with the CDC's National Electronic Disease Surveillance System (NEDSS) (Tsui et al., 2003). RODS has a Web-based interface for temporal and spatial analyses that can automatically classify chief complaints from hospitals into seven syndrome categories. The system connects to over 500 hospital emergency departments across the country and tracks chief complaints such as respiratory, gastrointestinal illness, botulinic, constitutional, neurologic, rash, hemorrhagic, and others (Chen et al., 2010). RODS also accounts for absenteeism and over-the-counter pharmacy sales.

The Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) also facilitates the detection of anthrax. The system is used throughout the country and compares the international classification of diseases, pharmaceutical sales, emergency room chief complaints (primary symptoms), and demographics to determine earlier detection (Foster, 2004). It also evaluates military ambulatory visits, school-absenteeism, and veterinary health records (Chen et al., 2010). As of 2003, ESSENCE functions in the NCR and 300 military clinics around the world (Chen et al., 2010). ESSENCE II also functions in the NCR and performs similar functions. This system collects, analyzes, and reports data to all NCR jurisdictions while allowing hospitals to share information with local and state health departments via secure nodes linked to a central node at Johns Hopkins Applied Physics Laboratory (Stoto & Morse, 2008). ESSENCE II can also display historic disease trends, provide inter- and intra-jurisdictional disease surveillance, and allow user communication (Stoto & Morse, 2008).

Chen et al. (2010) have reviewed other surveillance systems. The Rapid Syndrome Validation Project (RSVP) enables epidemiologists and health-care providers to communicate via Internet and review syndromes and make judgments of severity in order to perform spatial and temporal analysis. The National Bioterrorism Syndromic Surveillance Demonstration Program analyzes electronic records of over 20 million patients via participating health-care actors. Bio-event Advanced Leading Indicator Recognition Technology (BioALIRT) uses data from various patient records and attempts to improve detection speed by searching for unusual spikes in illnesses among military and civilian patient records, and near the NCR, it is used for monitoring purposes in Norfolk, Virginia. Other programs such as BioDefend, the Biological Spatio-Temporal Outbreak Reasoning Module (BioStorm), and Bio-Surveillance Analysis, Feedback, Evaluation and Response (B-SAFER) serve as additional technological tools for surveillance data collection and analysis. Georgetown University's Argus uses Internet technologies to gather information from World Health Organization (WHO) disease reports or ProMED unofficial reports, and the multilingual analysts involved can investigate a wide range of reports. The general public can also access databases dedicated to outbreak surveillance. The HealthMap website allows anyone to search a particular pathogen and view both official and unofficial reports around the world.

DHS has continued to improve surveillance as a result of Homeland Security Presidential Directive 10 (HSPD-10). The National Biosurveillance Information System (NBIS) continues to develop in the hopes of being a common operating picture (cop) of live information for Homeland Security and other relevant agencies to use (Rolka & O'Connor, 2011). This system aims to enable interoperability among agencies through information gathering and data analysis for the purpose of a unified response to bioterrorism.

Clinical testing and diagnosis is another mechanism at the forefront of post-exposure detection of a biological outbreak attack. The problem with these methods lies within the delay for the cultures to incubate or the assays to completely process which can take up to 2 days (Rao et al., 2010).

Some studies claim that syndromic surveillance is not a reliable means of early detection. A study shows that when presented with information outlining early *B. anthracis* symptoms, most physicians misdiagnosed the disease as pneumonia and influenza and only a few reported that they would order blood cultures which would imminently lead to the correct diagnosis (Stephens & Marvin, 2010).

Kong et al. (2008) presented an algorithm that can determine if an anthrax attack has occurred based on syndromic, meteorological, and geographical data. However, since this algorithm does not work until people begin to display symptoms of respiratory disease, this algorithm still takes between 48 and 58 hours to identify an anthrax outbreak. For a comparison, "a single hour of improvement in timeliness of detecting an aerosol release of [*Bacillus*] *anthracis* could save as much as $250 million of economic cost" as well as significantly decrease the number of casualties.

Additionally, there have been efforts by federal agencies to test the monitoring of potential aerosolized anthrax attacks within individual buildings. The EPA released a study in 2008 that compared multiple parameters to understand the primary reasons for the spread of anthrax throughout a building. The study analyzed cumulative exposure after thirty minutes and the amount of time for the agent to reach critical exposure within small and large buildings by multiple HVAC (heating, ventilation, and air conditioning) systems. The EPA looked at filtration efficiency, leakage, system recirculation, and building size in relation to room release to determine which parameters had the most significance to anthrax spreading as well as how each parameter affected the impact of the others. Large buildings were impacted primarily by the leakage rate between rooms, although the recirculation of air had indirect effects. Small buildings had similar results, except that when the filtration efficiency was low, this filtration had the most direct impact. The study concluded after additional testing that in-room air cleaners could reduce the amount of the agent within a room (Hawkins et al., 2008).

Michael A. Stoto, at Georgetown University, and Lindsey Morse, from Harvard University, assessed public health preparedness in the NCR by analyzing surveillance efforts. The study noted that several programs are in place in the region to survey for diseases, including ESSENCE II, a regional surveillance system developed by the Johns Hopkins University Applied Physics Laboratory (JHU/APL); the NCR Syndromic Surveillance Network, composed of epidemiological information from Maryland, Virginia, and Washington, D.C.; and the Regional Incident Communication and Coordination System developed by the COG. Despite these numerous attempts for interoperability, the study found is still a tendency for D.C. officials to only contact state health departments when attempting to spread information, while other nearby local health departments contact whichever health departments are relevant (Stoto & Morse, 2008). The wide array of systems and designated regions and actors makes a single, standard chain-of-command difficult to establish, although standardization is encouraged.

The CDC manages the LRN, a nationwide system of laboratories with pathogen-testing capabilities. Prior to 2001, the CDC, FBI, and Association of Public Health Laboratories assembled the LRN, which now incorporates state and local labs testing BioWatch (Shea & Lister, 2003). The LRN includes roughly 150 laboratories and can provide presumptive, but not confirmed, results for anthrax testing in about four hours. LRN personnel maintain communication with the CDC and other overseeing agencies in order to quickly relay results, in which case HHS and FBI pass on the information to numerous officials.

On the local level, the Maryland Board of Public Works approved design of a new state public health laboratory by the state's Department of Health and Mental Hygiene (MD DHMH) in January, 2010 (Dance, 2010). This and other lab developments can be incorporated into the response protocols.

In 2001, perception of the threat of anthrax increased with the Amerithrax attacks, the distribution of multiple letters with traces of anthrax spores to targets in American government and media. Performed in the wake of the September 11 attacks, the 2001 anthrax attacks further fueled fear of terrorism committed by religious extremists. Though there were only five envelopes sent out during this time, the attacks infected 22 people and claimed the lives of 5 of them. Another 31 people tested positive for exposure and 10,000 more underwent prophylaxis for the bacteria. Seven buildings on Capitol Hill and 35 mail facilities were contaminated. The FBI launched an extensive investigation into the attacks, analyzing everything from the spores to the handwriting of the letters. The FBI eventually pinpointed Dr. Bruce Edwards Ivins, a biodefense researcher at Fort Detrick, as a primary suspect. Even with warning signs of psychological and mental health problems, Dr. Ivins still had access to dangerous biochemical agents. Even though the investigation was inconclusive, evidence shows that there was a lack in security and psychological examination in government and military employment, leading to possible security leaks (DoJ, 2010).

Alexander Garza, Assistant Secretary for Health Affairs and Chief Medical Officer at DHS and former Director of Military Programs for the ER One Institute at the Washington Hospital Center, presented the biodefense programs of DHS. He stressed the importance of both experience and preparation, especially considering the number of lives that could be lost and the easy access to weapons (Garza, 2010). He noted that although the H1N1 virus was not very lethal, it did much to affect various industries and operations, from travel to workforce protection. Garza outlined three specific aspects of the DHS strategy. Technological advancement and innovation was the first component.

Special attention was given to the BioWatch program. Although it has done much to improve detection, the necessary testing must be streamlined. Garza then brought up the importance of expanding partnerships, especially partnering with FEMA and holding drills and annual discussion meetings. His final point was the combination of the former two, the synthesis of technology and partnerships. He noted that networks for plant, animal, and environmental health are all independent, and that they must complement each other and work together for researchers. This synthesis must be continued on down even to the state level.

2.2.3 Determination of a Response

An anthrax attack can be suspected through many possibilities. The first pathway would be that of direct observation, where an attack would be witnessed, and thus the authorities would immediately be contacted. The second pathway is a BAR, in which LRN directors, HEPRA, and local authorities part of the BioWatch Advisory Committee deem a BioWatch result a threat. The third is by the "astute physician," when a doctor recognizes that a patient may be infected with anthrax, and tests the patient for the pathogen. Finally, the last pathway is syndromic surveillance. All of these possibilities lead to various paths to decision-making, as we have covered in our Models of Interaction in Appendix B.

Ultimately, if an attack is suspected, a conference call is initiated that occurs among several health, emergency, and law enforcement authorities. It is on that conference call that a course of action is decided. In all likelihood, ESF #8 would be activated, leading to a full activation of emergency response by both the federal and local governments. The phase surrounding this conference call is filled with ambiguity and issues with chain of response, as the studies above have alluded.

The CDC released the *Public Health Emergency Response Guide for State, Local, and Tribal Public Health Directors, version 2.0* in April of 2011. It is intended to assist public health professionals in starting response within the first 24 hours of a crisis, to be used in tandem with existing plans and procedures. Like most plans in use today, the guide (CDC, 2011) conforms to the processes of the NRF and NIMS. It begins with a list of assumptions for preparedness, including the establishment of close working relationships with various actors, from local medical care providers and law enforcement to private businesses and academic institutions, and the development of objectives for response and systems for surveillance. The guide gives a detailed timeline of response. Immediate response, which happens in the first 2 hours, involves situational assessment, including affected geographical areas and critical infrastructures and consideration of other response organization, contact with key health personnel from administration, epidemiology, and medical staff, developing initial objectives, and participation in the nearest EOC. Immediate response, which takes place up to 6 hours after the beginning of a crisis, involves verification of operating health surveillance systems and laboratories, consideration of special needs citizens and volunteers, and updating of initial risk communication messages. Further response from 6 to 12 hours involves the collection and analysis of data available through surveillance and labs, the preparation of said data for coming assistance, and the assessment of health resource needs. The rest of the response period involves addressing the needs of mental and behavioral health support and preparing for transition to the next stage, whether it be extended operations or disengagement.

The Kansas Department of Health and Environment has established a set of guidelines for investigating bioterrorism that can be used regardless of geographic location (KDHE, 2010). The document stresses the need for an educated public in order to reduce the time for decision-making and initiate the response. The document also lists a set of protocols for the general public and officials to investigate anthrax, which include diagnosing the disease, finding the source, identifying additional cases, determining public health concern, controlling/preventing further outbreak, communicating, and educating as well as distributing a number of prescriptions and vaccinations. The plan also stresses the need for interoperable communication between emergency personnel, police, National Guard, media, political leaders, and the general public. Plans on several levels of government suggest a similar need for coordination.

2.2.4 Responding

Many of the actors during a response would communicate through radio and conference calls, and programs such as the Homeland Security Information Network (HSIN) and Web EOC. However, not every actor has a presence in all of these means of communication.

The Strategic National Stockpile (SNS) contains prophylaxis and medical supplies with the purpose of being distributed in times of public health emergencies on a massive scale. The CDC has authority over the SNS, but each state and Washington, D.C. has an allotment that it can request to the CDC for distribution during an emergency. DCDOH also has its own allotment of supplies that could be used to treat responders prior to the distribution of the SNS. Following the distribution of SNS to PODs, employees of the DCDOH, the volunteer agency DC Responds, the MRC, and various private sector charities such as the American Red Cross would help to dispense the prophylaxis to the public. Potential contacts, casualties, and missing persons would be tabulated and recorded. Meanwhile, in accordance with ESF #8, private sector actors and the United States Postal Service (USPS) could have individuals deliver prophylaxis to the homes of people who may be disabled or otherwise unable to go to a nearby POD.

PODs would allow for a single member of a family to come and pick up medicine and information. The families would know where to go because of public announcements initiated by HSEMA. It is also likely that all government employees would be made aware through announcements by the Office of Personnel Management and announcements through government channels.

State and federal officials agree that when an emergency response is required, medicines will be dispensed within 12 hours (CDC, 2008). The CRI encourages a 48-hour deadline to establish PODs at 72 CRI cities and distribute prophylaxis antibiotics and counter-measures throughout the country, with the prophylaxis supplies coming from the SNS (Hupert et al., 2009; Prevention, 2010). If the POD network is found to be inadequate in servicing all of the population in need, the USPS will be authorized to expedite the POD distribution of supplies (CDC, 2004).

New efforts have been made to prepare physicians for treating patients during an attack. The CDC developed online educational resources to help doctors identify anthrax and other potential bioterrorist agents, and studies showed significant improvement in diagnosis and management of all diseases (Cosgrove et al., 2005). The study was limited to physicians with interest in learning about bioterrorism and it did not address long-term retention. Nevertheless, it showed the new focus on improving the response to bioterrorism on the most direct level and the potential for medical professionals to speed up the response if properly trained.

A quantitative analysis also exists for the CRI where a time-transition model was utilized to describe the dynamic interaction between the progression of *B. anthracis* symptoms and the rate of dispensing and utilizing prophylaxis under CRI guidelines. Using a multitude of parameters, the model produced detrimental results for the hypothetical post exposed population if the CRI campaign is delayed or not coordinated properly (Hupert et al., 2009). Research was also performed utilizing models taking into account the pattern of airborne spore dispersion, disease progression, and queuing systems for prophylaxis and hospital care. The results of the models addressed concerns in the response from a need for more aggressive prophylaxis campaign to a need for responder training (Wein et al., 2003).

Kathleen Sebelius, HHS Secretary, presented the HHS's take on Biopreparedness (Sebelius, 2010). She began her term as Secretary with the H1N1 scare, giving a detailed description of the steps taken to mitigate disaster. HHS's supervision of CDC and coordination with NIH was of the utmost importance, with the CDC managing the receipt of lab kits by public health labs, and the NIH co-developing a vaccine. The state and local levels were instrumental in the distribution of the vaccine. Sebelius expressed that they were "lucky," especially since they had a new system in place, noting that "over-prediction" may have led to success. She noted that CDC reports indicated recent progress, from health departments to labs, but ultimately, vaccination rests with scientists on the field and doctors with vaccines. Even with progress, much remains to be done. She advised that more investments be made in countermeasures. Some of the fundamental problems rest in the dated technologies for vaccines, many not updated since the 1950s. In the years since, new ideas had been dropped and investment, especially from the private sector. In the end, much work must be done in innovating both vaccines and equipment. Sebelius outlined further plans, from upgrading the regulatory science pipeline to creating a non-profit corporation to provide support to and make investments in small medical companies.

Outside of the NCR, other efforts for emergency preparedness have demonstrated the developing capabilities of relevant actors and the general public. In Tucson, Arizona, a 2002 conference and training exercise included analysis of a multi-level response to an emergency (Caid, 2003). Over 500 of the attendees were from fire departments, police agents, physicians, pharmacists, private citizens, and private sector business across the United States. The CDC, U.S. Public Health Service, state and local emergency management and health departments, and people from as far away as Hawaii and Kazakhstan attended as well. The specific exercise involved a covert biological release in Mesa, Arizona, and an intentional anthrax release in Tucson. MRC volunteers and the Arizona National Guard worked with the community to receive, store, and stage (RSS) the "push-packages" shipped from the SNS. The participants intended to process 1,000 people during a six-hour clinic, and they managed to process 2,015 with the knowledge that they could have served as many as 10,000 given the same parameters. The exercise demonstrated capabilities and discrepancies, and such exercises give remarkable insight regarding a jurisdiction's emergency preparedness.

2.3 Information Technology

Both the government and the private sector have made efforts to enhance information-sharing through innovation. On the government level, multiple agencies have been developing and discussing implementation of Virtual USA (vUSA), a government effort to unify all coordination and communication while maintaining the necessary security. Stakeholders believe that in order for vUSA to be effective, it must create visuals for the geographic locations of jurisdictional emergency vehicles actively participating in a response as well as provide tracking of mutual aid equipment calls that involve interjurisdictional cooperation (NCR Geospatial Data Exchange 2011). vUSA has not been implemented officially in the NCR, but it has been tested in other parts of the U.S. More specifically, the DHS Science and Technology Directorate has operated a pilot version in Virginia, where vUSA "has reduced response times to incidents involving hazardous materials by 70 percent" (National Public Safety Telecommunications Council, 2011). Discussions regarding security clearance for specific pieces of information and linking multiple components of the response protocols (epidemiology, hospital care, criminal investigation, prophylaxis dispensing, etc.) continue with the hope of eventually using vUSA in the NCR.

The private sector has also provided innovative options for information-sharing purposes. IBM has a number of IT systems and products that have aided military efforts and could possibly contribute to civilian causes. Service oriented architecture (SOA) equally delivers information relevant to decision-making to people on scene (e.g., in battle) and to those in the office (IBM, 2009). The goal is to establish interoperability among previously separate systems and transition from "need to know" to "duty to share"

(IBM, 2008). Productive IT must provide real-time, authentic, and relevant information to its users. In order for IT to have a significant impact, changes in equipment must be complemented by changes in the processes and procedures necessary for using them (IBM, 2004). Technological innovation that cannot be used serves little purpose in the effort to improve timeliness, coordination, and communication.

Other efforts to improve information sharing include the Geo-spatial Common Operating Picture (GEOCOP) which we have learned about from one of our IT systems contact. GEOCOP is a website that integrates social networks in real-time to provide actors with updates within five minutes. The site has thirty-second reporting capabilities and has both an unsecured interface for the general public and a secure interface for the U.S. This private sector innovation can either be viewed as support or competition to existing information-sharing systems, and can be compared to Virtual USA. TACTrend is another website used by 500 police agencies as well as public health, medical, and military personnel to see and reveal information. While all IT innovations can be considered improvements by different experts, the users must have established identification keys in order to maintain credibility while using an IT product. Another potential problem is power failure during an incident. If there is no phone or Internet during an anthrax attack, the response effort faces severe problems and delays from detection to prophylaxis. One IT product attempting to address this issue is the flyaway kit, which connects as many as ten IP addresses from laptops to a satellite. Such technology has just been developed and is not currently in use while other projects may be in the works to address similar scenarios.

2.4 Quantitative Models for Team BIOCOUNTER

2.4.1 Plan for Team BIOCOUNTER

In preparing for our research, we examined methods by which the team could test out the recommendations developed in SSM. These quantitative methods mostly involved graphing and mapping the spread of an anthrax dispersal cloud. Doing so would help the team more fully understand the scope and consequences of an aerosolized anthrax attack, from the range of infection to the chance of massive casualties. For this, we researched various plume modeling programs, as well as equations to determine the chance of infection among the population given the amount of anthrax released.

We also researched a method by which we could easily and accurately depict a visual representation of the entire system of interactions among the various actors involved in response and investigation. For this, we were directed to graph theory, a mathematical method of organizing data into an organized visual representation. In a visual representation, in addition to displaying the information, we sought to organize the data in tiers and groups, visualizing specific relationships and determining the more important agencies, which of course would have the most connections in the graph. Furthermore, we ran different algorithms to determine the shortest and most frequent subpaths between actors.

The National Consortium for the Study of Terrorism and Responses to Terrorism (START) is an academic institution centered at the University of Maryland, College Park. It was established in 2005 with the express purpose of researching the various fields and issues involved the study of terrorism, from methods and means to psychological profiling and community action (START, 2010). START provides a number of articles and research projects on bioterrorism, as well as healthcare and communication studies in response to an attack.

START also hosts the Global Terrorism Database, a service that provides basic information on all terrorist attacks from 1970 to the present, offering a wide range of information for each attack, from the perpetrator and target to the method and means (GTD, 2012). The site also provides these statistics using very organized visual representations. We gathered basic information on past anthrax attacks from this database.

2.4.2 HYSPLIT

HYSPLIT is a dispersion model developed by the National Oceanic and Atmospheric Administration. HYSPLIT can map the trajectory of airborne particles. Other models discussed included the CALPUFF model. However, due to CALPUFF's steep learning curve and non-user-friendly interface, HYSPLIT was chosen due to its functionality and user-friendliness.

2.4.3 ArcGIS

ArcGIS is a mapping program developed by ESRI, a company dedicated to the development of geographical information systems. We chose this program to map because of the level of detail that ArcGIS is capable of producing, which would help us map changes on a smaller scale, as well as the ease of access, as opposed to more expensive programs.

2.4.4 Graph Theory

The numerous local, state, and federal agencies, private sector actors, individuals, plans, technologies, and systems have specific roles in prevention, detection, investigation, decision-making, and response to an aerosolized anthrax. In order to best represent all of these people and resources, BIOCOUNTER has implemented graph theory in order to offer an organized visual representation of the interactions among actors during all phases: detection, investigation, decision-making, and response. Each entity is represented as a node, and their communications and superiors are represented by edges that connect the nodes accordingly. Using a Microsoft Excel spreadsheet to represent all of the information as a matrix, the graph was constructed using the program yEd Graph Editor. Analysis of the graph involved distinguishing which sets of actors interact with one another in some capacity and identifying paths that may not include certain relevant agencies (Trudeau, 1993). BIOCOUNTER used the analysis to identify discrepancies in the real-world response protocols.

2.4.5 MATLAB

MATLAB is a mathematical computing program that allows users to design and run M-files. These M-files can include mathematical functions, algorithms, and input data from matrices. MATLAB can, therefore, analyze our matrix used for the graph and determine subpaths between actors and the most frequent subpaths possible.

2.5. Summary

The literature review provided insight regarding detection technologies and methods, investigative protocols, federal and localized policies guiding decision-making, and forms of response. By understanding the history of the anthrax threat and studying both current protocols and the principles behind them, we were able to develop rich pictures and root definitions of the current system and idealized models of interactions. These developments are discussed in detail in Chapter 3.

3 Methodology

3.1 Overview of Soft Systems Methodology

We found Soft Systems Methodology (SSM) to be the most appropriate methodology with which to conduct this study. Researchers utilize this methodology to describe and understand complex issues, specifically those that involve managing multiple human parties. These parties can hold multiple perspectives of various issues relating to the system, and can have many problems involving the multiple interactions throughout the system. These are true for the case of counter-terrorist methods; there is a different method of response for each actor (although they may resemble one another) that can cause confusion within the interaction. Mingers (2009) states that SSM addresses "messes" that require improvement rather than traditional scientific inquiries that usually require both a simpler solution and mathematical calculations.

SSM consists of seven steps, as Figure 3.1 demonstrates: (1) describing the problem situation, focusing on its history and scope; (2) forming a rich picture of the issue at hand, and understanding how parties perceive other parties (Checkland, 2000); (3) establishing the root definition, or the brief description of the system in which it includes what, why, and how the system operates (Ibid.); (4) developing models of interactions between the multiple parties involved in the process, based on the root definitions; (5) using the models as a guide to relate the rich picture to the root definitions, and clarify discrepancies in the system; (6) determining what changes will be feasible and desirable; and (7) reaching an agreement with all parties to adopt new procedures to improve the issue (Bentley, 1993).

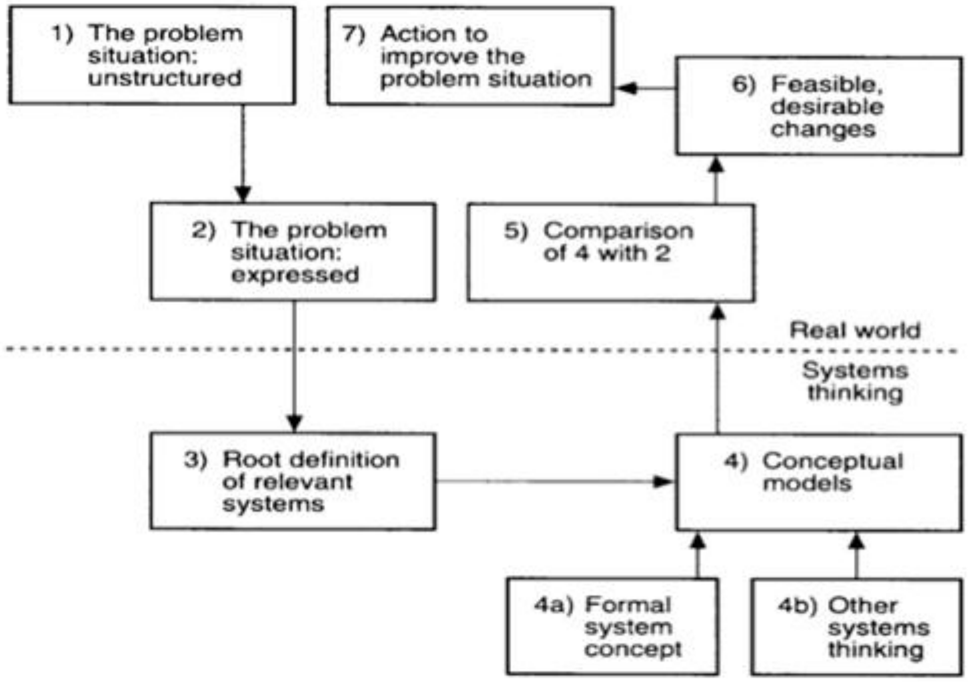


Figure 3.1 – Soft Systems Methodology (Ho & Sculli, 1994)

The first two steps of SSM are largely complementary. The problem situation in step one refers to a list of real world issues, which are then expressed in the form of a “messy” sketch, the rich picture. The methodology then switches from the real world to systems-thinking (Checkland, 2000). Here, the problem situations are condensed into a series of root definitions that are defined through their place in the system. Systems-thinking continues during the process of modeling the concepts of the root definition. The interviews that we conducted with individual actors were used to advise steps one through four, as well as to compare with the resulting models of interaction. In SSM, however, the models are primarily compared to the problem situation, in the real world. Feasible and desirable changes are then made based off discrepancies found in these comparisons, leading to the final step, taking action.

A central part of SSM is referred to as the acronym CATWOE: Customers, Actors, Transformation, *Weltanschauung*, Owner, and Environment. CATWOE supplies the guidelines on which the root definitions, and thus the entire methodology, rely. When looking at a mess, CATWOE provides a means to analyze the systems objectively. The customer of each goal was the party that benefits from the accomplishment of the goal. The actor of each goal was the party who facilitates the accomplishment of the goal. The transformation was the description of the state of things from the start point to the achievement of the goal. The *Weltanschauung* described the worldview of the goal; in a sense, it was the context of the goal. The owner was the single party to whom the achievement of the goal could be ultimately attributed. Finally, the environment consisted of the factors that affect but do not control the achievement of the goal, such as financial and ethical constraints. The use of CATWOE will be further explained throughout this chapter.

3.2 This Study's Methodology

For our study, we amended SSM to include elements of graph theory and computer simulations. As displayed in Table 3.2, we included instruments of graph theory subsequent to formulating the standard root definition of SSM, and prior to designing the standard models of interaction. We also included computer simulations following the models of interaction and prior to the comparisons. Each step of our study will be elaborated further in this chapter. In addition to these chronological steps, we also conducted numerous interviews throughout the course of this study. Our interview process will also be the focus of section 3.4.

	Soft-Systems Methodology	Amendments
1.	Problem Situation	
2.	Rich Picture	
3.	Root Definitions	
4.		Graph Theory and Matrix
5.	Models of Interaction	
6.		Computer Simulations
7.	Comparisons	
8.	Feasible and Desirable Changes	
9.	Taking Action	

Table 3.2 – Steps of This Study's Methodology

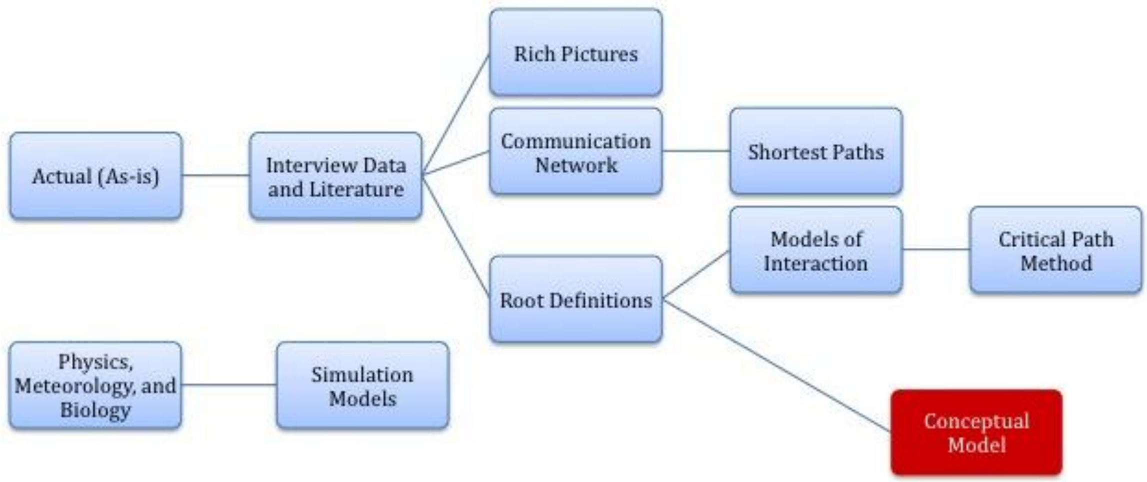


Figure 3.2 – Analysis Schematic

We also constructed an analysis schematic (Figure 3.2) to further integrate the SSM as we continued our research. The main two areas of focus were (1) the actual setup of the response process between the numerous agencies involved as it is now, and (2) the science behind an aerosolized anthrax release that led into the creation of our simulation models. For the first area, study of the "as-is" situation came from interviews with key individuals well as extensive literature review. These would then go into constructing our rich pictures network of shortest paths between the interconnection agencies), and our root definitions. The lattermost aided in construction our models of interaction and CPA of all of the interagency intercommunication, and the conceptual model of desirable and feasible changes for a more apt and streamlined response process. For the second, all of these scientific fields contributed to our understanding of how anthrax spores affect the body, how they travel across a large area over a 5-day period, and how meteorological patterns affect said travel. All of these were critical to the construction of our numerous simulation models.

3.3 Problem Situation

Based on existing research such as the ominous World At Risk report (Graham & Talent, 2008) and the expertise of inside actors we've spoken to, it was clear at the beginning of our research that we were dealing with what Checkland would consider a mess. We recognized that multiple adjustments could potentially be made to improve response time and coordination among actors.

We addressed what has been identified as the inefficiency of ready emergency response during an aerosolized anthrax attack (Hupert et al., 2009). With a lack of a clear chain of command that was expressed to us by a few of our interviewees, and poor coordination (Bush, 2004), this could potentially slow response time and place people at higher risk in the event of an attack.

When determining our problem situation, we made a list of twelve potential problems relating to the response to an aerosolized anthrax attack. To gather this list, we explored our literature review for known examples of issues pertaining to the topic, conducted our first interviews and searched for discrepancies among written response plans. These problems included the following:

- Redundant notifications of emergency events,
- Lack of communication at certain levels of the chain of command,

- Miscommunication at different levels leading to misunderstandings or false information,
- Lack of understanding of role capacity and responsibilities,
- Overlapping of role responsibilities,
- Lack of standardized guidelines among varying actors for a particular situation,
- Confusion as to who takes the lead or incident command in certain situations,
- Inconsistency in risk communication leading to public confusion as well as disrupted agency operations,
- Detection not rapid enough to elicit a response within 48 hours of exposure,
- Not enough time to perform prophylaxis for a large area or from repeated attacks,
- Cuts in funding thus changing logistics to adapt to new budget,
- Volunteers for POD sites who are not committed at all times

This large list had included many similar issues, and the sheer size of the list presented what could be an unmanageable situation for us to tackle. To move to the next step, the rich picture, we needed to decrease the number of problems we initially identified. As a result, we were able to sort many of the problems into more general issues, which resulted in the following list:

- Inefficient and unclear lines of communication and control among actors
- Managing interactions among agencies, volunteers, and the private sector
- Ambiguous standards of decision-making process

3.4 Information Gathering Interviews

In order to gather enough information to design the rich picture in the next step of our methodology, and later the models of interaction, we spent twelve months comprehensively researching the details and interactions of the numerous actors involved in emergency planning, management, and response of such an attack. First, we read several academic papers detailing and evaluating current response plans and past responses, and numerous response plans drafted by federal, state, and local agencies. Second, we made many contacts with the aforementioned individual actors, and conducted both informal and informational interviews with them.

Prior to conducting our interviews, we submitted an application to the University of Maryland institutional review board to ensure that our interviews would be approved by this university. The response we received stated that we did not need official approval of the board, as our research did not use personal information for our data.

We made contacts with individual actors through various means. First, we contacted many experts whose work we had previously found and reviewed. Through this means of contact, we were able to get in touch with an author of the CDC field guide for an anthrax attack. The second means was through personal contact. Our mentor, Dr. Jeffrey Herrmann, was able to get us in contact with a program manager at the Montgomery County Department of Health and Human Services. Personal connections we already had with some experts allowed us to speak to officials in the Maryland House of Delegates, the FBI, MedStar Health, and Johns Hopkins Hospital. Additionally, we attended the Northern Virginia Medical Reserve Corp monthly meeting in August 2011, where we came into contact with officials from the Virginia Department of Health.

Finally, we were able to contact the majority of our interviewees directly. Actors that we contacted in this way included officials and experts in the Maryland Department of Health and Mental Hygiene (MD DHMH), CDC, the Alexandria Department of Health, the Laboratory Response Network (LRN), the Frederick County Health Department, the District of Columbia Fire Department, the Washington Regional Threat and Analysis Center (WRTAC), the Metropolitan Washington Council of Governments, the MRC, the D.C. Homeland Security Emergency Management Agency (HSEMA), the Montgomery County Department of Health and Human Services Public Health Emergency Preparedness and Response Program, and the D.C. Health Emergency Preparedness and Response Administration (HEPRA). We also spoke to an expert on NIMS, a senior epidemiologist for the Montgomery County Department of Health and Human Servicesh, and an IT systems expert at HMS Technologies. In addition, we received additional input from subject-matter experts from Rutgers University and the Wyatt Technology Corporation.

Most interviews occurred over the phone, but a number were executed in person. We asked each interviewee prior to his or her interview for permission to record the interview. If the interviewee denied the request, we took thorough notes of the interview. The vast majority of interviews were recorded, however, and subsequently transcribed.

During the interviews, we asked questions specifically selected for the position of the respective interviewee. Generally, however, we used a series of standard questions for most of the interviews:

- What is your official title and what are your main duties?
- What do you do on a daily basis for your position

- How and in what way would your agency/organization/department be involved in the response to an aerosolized anthrax attack?
- Could you guide us through a time-referenced explanation of you and your agency/organization/department's activities when you are notified of a possible aerosolized anthrax attack?
- What is your main means of communications within your agency/organization/department and with other actors on a regular basis, as well as during an emergency?
- Are there any lingering issues you have witnessed in your capacity, including, but not limited to, issues with communication or chain of command?

We asked certain interviewees questions that we wrote as a reflection of publicly released response protocols and plans, including their role in certain planning and response exercises.

An issue we did not anticipate with our interviewees was the departure of officials from their positions subsequent to the interviews. Two vital emergency response officials within the D.C. government left their positions within six months of their respective interviews. We contacted their offices to discuss changes with their respective agencies, but both of their interim replacements were unwilling to speak to us.

3.5 Rich Pictures

After gathering as much information as feasibly possible from literature review and the interviews, we created a visual representation of the response protocols in the form of an overarching rich picture and three sub-rich pictures. The rich pictures were a means by which we could display the environment in which the problem situation would arise.

The rich pictures marked the entry of the methodology from the real world to systems-thinking. In this respect, they did not require elaborate details, but instead sketched the overall relationship among actors. We paid close attention to the structure, processes, climate, people, conflicts and issues surrounding the problem situation.

Specifically, as our topic of study had three main realms—detection, investigation and decision-making, and response—we split our rich pictures correspondingly. Within each realm, which we placed in chronological order, we inserted sketches of general departments, agencies, and concepts, which would then feed into larger actors. We represented this feed with arrows. These three categories were displayed by each of the sub-rich pictures. The overarching rich picture provided an overall schematic of the current process that would occur from pathogen release to prophylaxis dispensing. Our rich pictures had the ability to display a coherent visualization of the complicated mess.

3.6 Graph Theory

We used several different applications of graph theory in the course of this study. Firstly, the models of interaction we constructed were based on preliminary diagrams that we formed with the software yEd and NodeXL. Secondly, by analyzing these preliminary diagrams with graph theory, we were able to use the results of our analysis to assist later in determining feasible and desirable changes to the system.

We consulted University of Maryland professors Dr. Justin Wyss-Gallifent of the Department of Mathematics and Dr. Michelle Girvan of the Department of Physics for guidance with regard to graph theory. Upon their guidance, we first compiled all of the information about the system we could gather into a single Microsoft Word document, and converted the information into a 401 by 401 grid Microsoft Excel matrix (our number of actors totaled 401). Each actor that is involved in emergency response—agency, department, and individual—is represented in one of the 401 columns and rows. This document then marked communications among these departments. Each communication that occurred between a selected row and column—two actors—was represented in the corresponding cell with a "1." All other cells were then represented with a "0." The matrix also provided directionality of communication. As shown in Table 3.6, a cell in row "m" and column "n" with a "1" indicates that entity "m" communicates with entity "n." This communication was not necessarily mutual. In order to establish mutual communication, the cell in row "n" and column "m" would also need a "1."

Sample Matrix	M	n
m	0	1
n	1	0

Table 3.6 – Matrix with Directed Communication

yEd and NodeXL have the ability to form graphic visualizations of large systems. We used both of these programs to display the interactions that would occur among actors during the preparedness planning, detection, investigation, decision-making, and response to an aerosolized anthrax attack, as they both had advantages. Both yEd and NodeXL accessed the Microsoft Excel matrix and represented every actor as a node/vertex on a graph. These programs converted the numeral indications of interactions within the matrix ("1" and "0" data entries) into directed edges between appropriate nodes.

yEd is a free application capable of generating high-quality diagrams ("yEd Graph Editor," 2012). The diagram it created emphasizes overall interactions, and showed us a basic outline of how truly messy the system is. NodeXL is another, similar diagram generating program that works within Microsoft Excel to provide a graph of the data ("NodeXL," 2012). Through grouping clusters together, we were able to divide the graph into smaller sub-sections to look at specific areas in the response process.

We later used graph theory analysis to obtain relevant information regarding the response protocols, e.g. NRF and NIMS. First, yEd and NodeXL ran "betweenness centrality" analysis on the graph. Betweenness centrality weighs each node based on the number of occurrences it appears within a path connecting two end nodes provided that the "between" node is not one of these "end" nodes. The nodes with the most occurrences were assigned the greatest weight, emphasizing its necessity within the network. By use of the Microsoft Excel matrix and MATLAB (version 7.12.0.635) via the University of Maryland A. James Clark Virtual Computer Lab, we were able to write an M-file to find the shortest path between any two selected nodes. The M-file implemented Dijkstra's Shortest Path Algorithm (Kirk, 2007). Our manipulation of this algorithm incorporated an "adjacency matrix" comma separated values (CSV) file that had only the binary code of directed communication, a separate CSV file with a list of corresponding entity names, and an output that identified the number of nodes in the shortest path, their order, and their names. Our shortest path M-file determined the path between two particular nodes that required the fewest number of total nodes; however, this file did include "end" nodes in the analysis even though betweenness centrality did not. This algorithm provided quantitative analysis of which actors can contact one another directly and if not, who else must be involved to establish communication or relay information.

Next, we developed another M-file that could sort all subpaths by number of nodes and frequency. We wanted to see the five most frequent subpaths of each possible length. The output provided the number of possible occurrences of each stated subpath and listed the nodes in chronological order. Since these subpaths were determined based on mathematical possibility, some paths were expected to have relatively high frequencies compared to expectations. The longest subpath(s) identified by this M-file represented the diameter of the graph. Complicated networks need the diameter to be as small as possible to ensure efficient communication. All of the quantitative data from the graph and M-files were used to compare with other components of the research, and we were able to use these comparisons to identify previously subtle discrepancies and propose feasible and desirable changes.

3.7 Root Definitions

The root definitions are a group of underlying goals to be achieved during the course of the mess. In order to form the most thorough root definitions possible, we needed to organize our researched information. For every piece of studied literature, we made notes containing information relevant to the communications among actors. Likewise, we transcribed the interviews with subject-matter experts, which revealed important connections among relevant actors. Information from notes and transcriptions were organized by hazards, time, departments/agencies/regions, methods of protection, and supplies/programs into a single Microsoft Word document, with a supplementary document for additional interviews and pieces of literature examined after the first round of sorting. This compilation of all relevant facts allowed for a second sorting of information. All relevant facts pertaining to a particular organization, individual, plan, or system were placed under a heading for their respective entity. This single document contained all connections among actors for the purposes of transmitting qualitative and quantitative data. This database served both as a reference point in the formation of the root definitions and the basis of a Microsoft Excel matrix we later used in our applications of graph theory.

After compiling our database, we set out to define our goals. We applied CATWOE to each goal. The result was the description one broad goal in saving lives, and three descriptive goals that were part of the first.

3.8 Models of interaction

3.8.1 Overview

Models of interaction display how the actors would respond and interact with each other during the anthrax response if every procedure were followed ideally. Our models include information about how actors interact with one another, the procedures each actor follows, and how all actors involved with the response process rely on others in order to perform their associated tasks.

Based on the visual aids we constructed with our rich picture, yED, and NodeXL, we were able to easily construct four models of interaction, one for each root definition. As our models are each based off of one of the five root definitions, the specialized diagrams formed by NodeXL were particularly helpful.

In the formation of our models of interaction, we included all involved actors. We represented interactions with arrows pointing from one actor toward the actor to which the original actor reports. We also included time estimations for each interaction. These time estimates were based on required maximum time limits for certain interactions, originating in official response plans, as well as estimated timeframes we learned during our information gathering interviews.

The models were designed using Microsoft Project, which allowed us to easily display the data as a Gantt chart. We also included CATWOE information on each task along the chart. Model 1, based on the root definition to "save lives," was essentially a comparison of response times calculated in the other models with information acquired from the computer simulations. Specifically, it compared a single simulation from the Total D.C. Sick Hourly computer simulation with the response scenarios examined in the models of interaction.

3.8.2 Primary Discrepancy Identification

While the focal point for identifying issues related to an attack's response would be during the comparison step of our methodology, we did begin to identify some discrepancies as we formed our models of interaction. We listed the independent actions each actor is capable of running and placed those activities on a timeline. From this timeline, we noted odd overlaps in responsibilities. We then rearranged the responsibilities listed on the timeline in a more logical and efficient fashion by paying special attention to overlapping arrows, as recommended by Checkland (2000). In this step, we noted the environment limitations for each action, as included in the CATWOE for the relevant root definition. These changes were simply primary attempts to identify discrepancies, and were not our final conclusions. These discrepancies are referred to as primary because of the time at which they were identified, not because of the intensity or reach of the actual discrepancy.

The following analysis recommendations by Checkland (2000) served as guidance during this step:

1. An ongoing purpose – For each action taken by these actors, we investigated each for their particular reason and how that contributes to the response process.
2. A means of assessing performance of the action – Determining how effectively and in what capacity all of these actions were in performing their described duty.
3. A decision-making process – Figuring out how each of these actions is triggered to occur, and how/where/when.
4. Components that also function as systems (sub-systems) – Each of the actions that happens subsequently.
5. Components that interact – How that particular action's aspects and components interacted with others.
6. Environmental and area constraints – Built upon CATWOE, in how the environment and other limitations are imposed on the actor.
7. A boundary between the system and environment – Determining if there are limitations that exist that can separate the action from the environment it acts upon.
8. Resources required – Measuring the amount of resources, which includes funds, employees, as well as supplies, and how they contribute.
9. Continuity – What occurs afterwards?

We also maintained a document listing discrepancies as we came upon them throughout our research. This document included officials referring to outdated response plans, and discrepancies specifically pointed out by actors who we interviewed.

3.8.3. Determining Critical Paths

We rearranged our models based on root definitions into models based on release scenario in order to construct four complete chronological models. As it acted as the endpoint on each model, we only included information pertinent to the completion of the setup of PODs. This allowed us to determine the critical path in each scenario. After determination of critical paths, we focused especially on minimizing extraneous time spent on the tasks along the paths, during our subsequent analysis.

3.9 Computer Simulations

3.9.1 Overview

As discussed in Chapter 2, there are several studies that have examined aerosolized anthrax releases in Washington. While these studies focus on factors such as the expected number of casualties for a certain release of aerosolized anthrax, none of the studies present exactly what we require for our study. Our study is concerned with the decision-making of officials within the first several hours after an anthrax release. The actors will be getting data about the scale of the attack, as well as who exactly is at risk, during the CAP. Consequently, we developed a model that will predict on an hour-by-hour basis the location of individuals who will begin experiencing symptoms of anthrax exposure, based on past meteorological data and varying release scenarios.

Aside from BioWatch and intelligence, the only information actors will be able to access during a response is that which is acquired via syndromic surveillance. At the start of our research, we concluded that in order to display information akin to that which would be supplied to the actors in an actual attack, we would need an active map that would mark in time the location of people who would begin to exhibit these symptoms.

Results from this simulation were incorporated directly into our models of interaction. The models of interaction analyzed the response to an attack through a time by time basis; therefore, this simulation provides information as to what the actors might see on the same time scale.

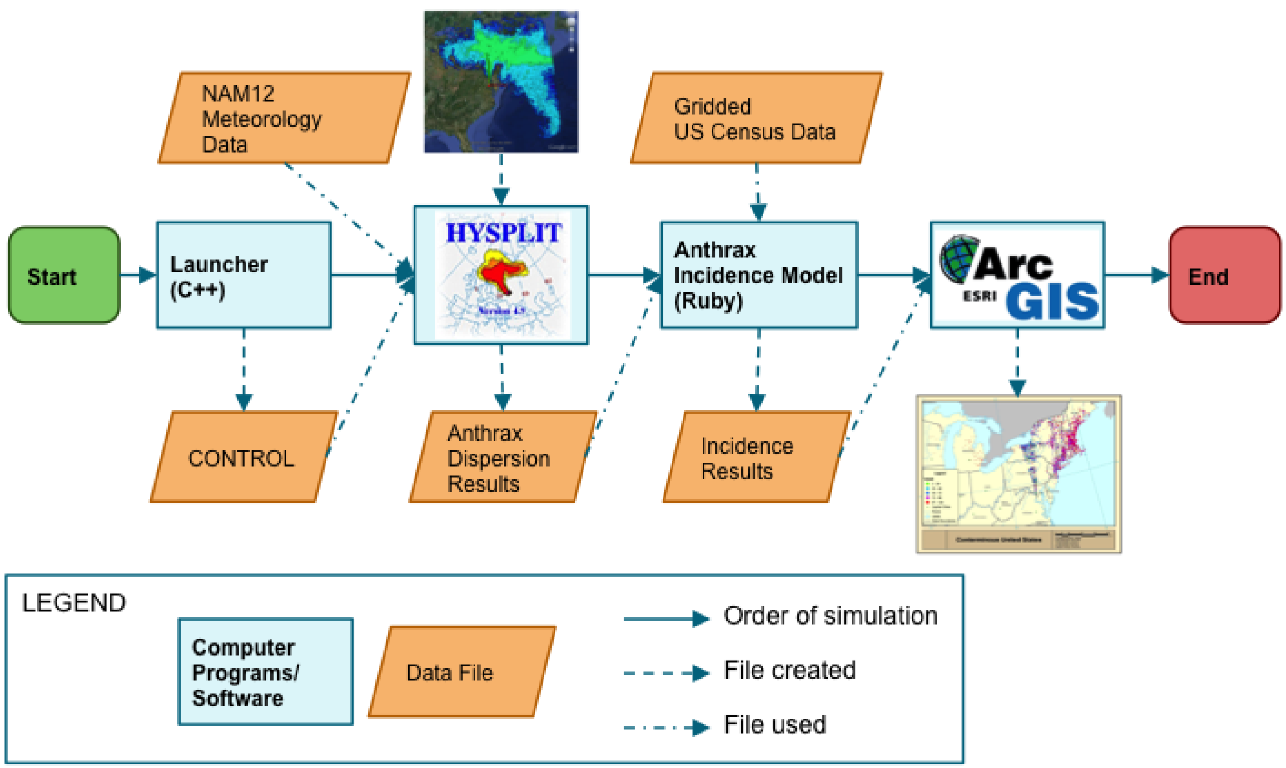


Figure 3.9 – Simulation Overview

Figure 3.9 demonstrates the simulation process for this study. Each simulation began with situational inputs that we entered into the launcher we formulated specifically for these simulations. Into this program, we were able to enter dates and release points for the anthrax to be released, as well as other parameters, which we will further clarify in the results chapter of this paper. HYSPLIT created the concentration file through simulations that are put into a gridded cell form of latitude and longitude. These files were then passed to our Anthrax Incidence model, via the same launcher. The Anthrax Incidence model took the data from HYSPLIT and calculated the number of sick persons in each cell. The population of the cells originated from the US Gridded Census Data 2010. The file generated by the model was a Comma-Separated Values (CSV) file, viewable as a spreadsheet in Microsoft Excel. Latitude, longitude, and hour are given for each ill person. ArcGIS took this file via a Python script and placed it on a visual map of Washington, as well as other affected parts of the East Coast. The map was then able to display the location of individuals who had become sick with reference to time.

The basis for these simulations comes from specific case studies that we have gathered from our research. The first case study is the anthrax outbreak in Sverdlovsk, Russia. While the results of the accident were tragic, they still provide us with a wealth of information for our simulations, providing us with helpful meteorological and geographical data. They included data of incubation periods, number of people infected, the direction that the anthrax traveled in, and an expansion of previous research. The formula we used for our simulations was based off of research on the Sverdlovsk case study (Brookmeyer et al., 2005). We found that his model to be the most ideal and effective for our research.

The first model designed in the Sverdlovsk case study was the competing risks model, which defined the cumulative attack probability function of disease, $F(t)$, to be the cumulative probability that a person develops disease in less than *t* days following exposure. Following this, they create a model for the incubation period distribution, defined as *F(t)*. This resulted in the formula:

$$F(t) = 1 - \exp\left[\frac{-D\lambda}{\lambda + \Theta}\left(1 - e^{-(\lambda+\Theta)t}\right)\right]$$

There are three parameters described in the cumulative attack probability function shown in the above figure: the germination rate λ, the clearance rate θ, and the dose of inhaled spores *D*. The function *F(t)* increases as either the dose or germination rate increases, or the clearance rate decreases.

The research on these formulas also developed constants for us to use for our model. By using the estimate of the clearance rate derived from animal studies, the research was able to predict the incubation period of disease observed in humans in a low dose outbreak such as in Sverdlovsk. The median incubation period based on the competing risks probabilistic model with $\theta = 0.07$ per day was 9.9 days. The germination rate λ was solved to be at 5×10^{-6}. We incorporated the formula F(t), as well as the constants, in our simulation, which we used in our anthrax incidence model which will be discussed in Section 3.9.3.

3.9.2 Dispersion Model

One of our team members met with Dr. Tim Canty in the University of Maryland Department of Atmospheric and Oceanic Science on a weekly basis during the summer of 2011 to discuss how to approach modeling the dispersion of anthrax in the atmosphere. We considered in an instantaneous release of anthrax, as opposed to a steady state model. According to the EPA's recommendations, CALPUFF Modeling System is the preferred model for a non-steady state dispersion model (CALPUFF, 2012). After researching CALPUFF, we found that the model had a steep learning curve and did not have a user friendly GUI. Because of this, we decided to use the HYSPLIT model. That same team member also attended a three-day HYSPLIT workshop hosted for the NOAA Air Resources Laboratory by Earth Resources Technology, to learn how to use the software.

HYSPLIT is a comprehensive system for calculating aerosol trajectories within a dispersion simulation (HYSPLIT, 2012). The HYSPLIT program is capable of creating plume model simulations over a particular area and tracking the concentration of anthrax by latitude and longitude. It can then generate a CSV file showing the anthrax concentration after release over a gridded map at varying hours and days.

The HYSPLIT model requires various pieces of information about the particular simulations in order to run successfully. For our HYSPLIT model, we used archived NAM12 meteorological wind pattern data, which is freely available for download in single day formats and can be found on HYSPLIT's website. HYSPLIT also requires particle properties, release properties, and dispersion properties in order to trace proper trajectories. The particle properties describe the properties of anthrax, such as the size of an anthrax spore. The release properties describe the starting time, location, and amount of pollutant released. The dispersion properties adjust the options for the manner in which HYSPLIT runs its computations. HYSPLIT reads in dispersion properties from a SETUP file, and all of the other properties from a CONTROL file. For a complete list of the parameters that were kept constant for each simulation we ran, see Appendix D.

We performed a set of simulations, varying time of release, and amount of anthrax released. See Appendix D for a list of the parameters we varied. These simulations will be discussed in more depth in the results chapter of this paper.

As described earlier in the flowchart, in order to automate the dispersion simulations, the HYSPLIT program was run from C++ instead of from its GUI. The C++ program is referred to as the "launcher." The launcher allowed us to run many simulations in a row while changing one variable at a time. The launcher also ran the other components of our simulations such as the Anthrax Incidence Model. Through the launcher, the different components of the simulation can communicate with each other. The source code for the launcher can be found in Appendix D.

3.9.3 Anthrax Incidence Model

The results of the anthrax dispersion model were used in conjunction with the Gridded 2010 Census Data as data used by the Anthrax Incidence Model. This model analyzed each grid cell. Based on the number of people in each cell and the concentration of anthrax in the atmosphere at each specific time, the model calculated the point in elapsed time at what time each person in the grid cell developed symptoms.

Although there are several pre-existing models of anthrax incubation and the chance of developing symptoms as a function of anthrax dosage, few of these models work for exactly our purposes. These models only provide a function that considers the amount of anthrax introduced to the body when determining whether a subject will develop symptoms. In our model, the anthrax was inhaled on an hourly basis, whereas the other models assume that all of the anthrax is inhaled at one instant. As a result, we used Brookmeyer, Johnson, and Barry's model of anthrax incubation as the basis of our model.

This model accounts for the biology of spore clearance and germination, and thus considers the introduction and exit of spores to and from the body. We were able to modify the model to account for anthrax inhaled at specific time intervals.

The aforementioned equation for F(t) is a Poisson approximation to a binomial distribution. The equation equals 1 – the probability that no spores have germinated after a certain amount of time. Instead of considering a value of t on the order of our entire simulation, we considered only a small timestep Δt. Therefore, $F(\Delta t)$ gave the probability that at least one spore has germinated within the timestep). We used the function $F(\Delta t)$ in a stochastic model of anthrax dispersion that is applied to an individual person. This model acted using the following algorithm:

1. Determine how much anthrax D is in the body at the current time T. D changes with time, so it is assumed that D = D(T)
2. Calculate the probability of getting sick in a certain timestep $F(\Delta t)$
3. Generate a random number between 0 and 1
4. Compare the random number to the probability $F(\Delta t)$.
5. If the random number is less than $F(\Delta t)$, then a spore has germinated. In this case, the person will become sick and the algorithm ends
6. Else, no spores have germinated. Therefore, increment T by Δt, and go to step 1

Step 1 was computed using the formulas below. These formulas assumed that all of the anthrax inhaled during a timestep was inhaled at the start of the timestep.

- c(T, latitude, longitude) = anthrax concentration [pg/m^3]. This value has been determined from the dispersion model, and there is a value for each timestep, and for each grid cell. For this set of equations, however, we only looked at a specific grid cell, so we will consider c(T).

- breathing rate = volume of air inhaled per unit time [m^3/h]
- spore weight = weight of an individual spore [pg]
- Δt = timestep [hours]
- T = current time [hours]
- SporesInhaled(T) = c(T) * (1 /spore weight) * breathing rate * Δt [spores] = number of spores inhaled at time T
- SporesCleared(T) = D(T-Δt)*ϴ*Δt = number of spores leaving the body at time T
- D(T) = D(T-Δt) + SporesInhaled(T) - SporesCleared(T) = Total number of spores in the body at time T

As this algorithm ran, there was a chance that all of the anthrax could have cleared before any germination. The probability that this would occur was given by $lim_{t\to\infty} F(t)$ which Brookmeyer gives as the attack rate AR, where:

$$AR = 1 - \exp\left[\frac{-\mathrm{D}\lambda}{\lambda + \Theta}\right]$$

For implementation purposes, we could only run the stochastic model for a finite amount of time. Since the focus of this study was the immediate response to an aerosolized anthrax attack, we could assign an end time to the stochastic model to determine if the person developed symptoms by the end time of the simulation.

The stochastic model was applied to every person within a grid cell to create a binomial distribution. This binomial distribution algorithm looked at every person in a grid cell, which adds to the stochastic model as follows:

1. At the start of the simulation, everyone in the grid cell is not sick. The total number of people in the grid cell is given by the 2010 Census Data.
2. Determine how much anthrax D is in the body at the current time T. D changes with time, so it is assumed that D = D(T)
3. Calculate the probability of getting sick in a certain timestep $F(\Delta t)$
4. For each person not yet sick in the grid cell at the start of this step
    a. Generate a random number between 0 and 1
    b. Compare the random number to the probability $F(\Delta t)$.
    c. If the random number is less than $F(\Delta t)$, then a spore has germinated. In this case, the total number of people sick in the grid cell is incremented, and the total number of people not yet sick is decremented. In addition, the number of people who got sick at this hour in this grid cell is incremented.
    d. Else, no spores have germinated
5. Increment T by Δt and go to step 2, unless there is no one not sick in the grid cell or T == end of simulation time, in which case end the algorithm

The binomial distribution algorithm was applied to each grid cell that we analyzed. The results of one grid cell did not affect the results of another grid cell, and the binomial distribution was used to analyze each grid cell individually. The binomial distribution algorithm applied to every grid cell was our Anthrax Incidence Model. This model is implemented in Ruby, and the Ruby code for this is shown in Appendix D.

The end result of the Anthrax Incidence Model was a 3D array of people who became infected during the course of each simulation, based on grid cell latitude, grid cell longitude, and time.

3.9.4 Mapping the Potentially Sick Population

The Anthrax Incidence model generated a Comma-Separated Values (CSV) file that was passed along to ArcGIS. It was a geographic information systems program that was capable of putting a point on a map at the location for every person who could potentially become sick according to the CSV file (ESRI, 2012). These points are exact coordinates calculated along the latitude and longitude of each person. However, to prevent persons from overlapping with the same latitude and longitude, the Population Model adjusted the location's latitude and longitude by a small, random amount between 0 and 1, multiplied by 0.0083 (the size of each cell). We used this to visually demonstrate the effects of an anthrax attack on the population according to the simulations ran.

3.9.5 Experiments

The launcher program allowed us to keep most of the inputs constant and varying only the ones we want to vary individually. We specifically varied the date, amount, and location of anthrax release. We used 4 days and 4 varied amounts, and 1 location within Washington, D.C., resulting in 16 total simulations. A detailed list of variations can be found in Appendix C.

3.9.6 Total D.C. Sick Hourly

For use in Model 1, we made a case study in which we analyzed on an hourly basis how many people would be infected, roughly within the beltway. This specific study was referred to as "Total D.C. Sick Hourly."

We took as an example Simulation #7, the release on June 9, 9am 2010, 1kg release. The specific coordinates we considered inside the beltway formed a box with top-left corner (38.789416^0 N, 77.177582^0 W) and bottom-right corner (39.007553^0 N, 76.876831^0 W). We then plotted the number of people infected versus time for Simulation #7.

3.10 Comparisons

Because each of our models of interaction were based on a corresponding root definition, which in turn is a systems-thought representation of the real world, our models of interaction are part of systems-thought. Consequently, we were able to compare these models to the real world.

When we approached our comparisons, we first determined and examined the critical paths in each model of interaction. We then compared the most important tasks on each critical path to the most interactive nodes on our yEd and NodeXL models, to search for major differences. Next, we compared the critical paths to our rich pictures, to see if the paths along the rich pictures actually corresponded to the critical paths. Finally, we examined Model 1, which was in and of itself a comparison of our models of interaction and our computer simulations. We named the discrepancies we identified in this phase the secondary discrepancies. Our secondary discrepancies are those that we identified as a result of comparisons, as opposed to through prior review. Secondary discrepancies are not any less important than primary discrepancies, and are so named because of the timing of their identification. The results of our comparisons gave us a large list of discrepancies between the real world and optimal efficiency, between actors, and within the overall system.

3.11 Feasible and Desirable Changes

We considered both our primary and secondary discrepancy identifications to generate our suggestions. We analyzed discrepancies through the perspective of CATWOE so that each analysis gave us a different idea about how to improve the response process and gave us different systems to work with while designing our suggestions to the numerous actors involved.

In order to determine an optimal path, we looked again at our critical paths, to see what the most critical tasks are currently. This gave us an overview to determine where events could be streamlined or removed for redundancy in order to form a more efficient method of response. Numerous models were made and each of these were examined to determine what changes could feasibly be made to reach the desirable outcome of a refined system.

3.12 Taking Action

Our conceptual model outlining our feasible and desirable changes is discussed at length in Chapters 4 and 5. Overall these changes display which agencies would participate in specific actions and included times necessary for each action. We have agreed to send our thesis to HSEMA, D.C. Fire EMS, Montgomery County Health Department, VDH, MRC, and CDC for evaluation and critique. Upon thorough discussion of the proposed changes, the conceptual model and thesis will be sent to relevant actors including the previously listed agencies as well as the Metropolitan Police Department (MPD), D.C. DOH, DHS, FBI, and American Red Cross.

4 Analyses of Quantitative and Qualitative Data

Our fourth chapter is organized as follows: Section 4.1 describes our analysis of the communication network in the system, first organized in matrix form on Microsoft Excel, then more fully visualized utilizing graph theory, which helped us identify key agencies. We used algorithms such as betweenness centrality (BC) to determine the shortest paths in the communication network as well as existing redundancies. Section 4.2 describes our development of rich pictures, as suggested by SSM. These rich pictures, visuals of the system as it is, were compiled using information from our literature and interviews. Section 4.3 describes the next step in SSM, the development of root definitions, which lay out the purposes and goals of the entire system. Each of these, detailed using the CATWOE elements, contributed to the development of an idealized model of interaction. Section 4.4 describes our simulation work. We simulated the hypothetical dispersion of aerosolized anthrax from Washington, D.C. and estimated the range and concentration of the aerosol cloud. We also predicted the number of people who would likely become ill from a dispersion using a model that matches population data and dispersion information. Section 4.5 describes the development of models of interaction, another step in the SSM. Each model deals with a different scenario of detection, each with varied times, actors, and varying efficiencies. In determining the critical paths of each model, we were able to isolate further discrepancies and redundancies, all of which led us to develop our suggestions of feasible and desirable changes.

4.1 Communication Network

We established a communication network of all actors involved in detection, investigation, decision-making, and response through the compilation of information from the literature review and interviews. Implementation of an adjacency matrix, which represented directed communications between actors, and its analysis using both graph theory software and MATLAB produced rich pictures that represented the passing of information in systems, actors, and individuals throughout the CAP.

4.1.1 Matrix Representation

We used the categorized information from our literature review and interviews with experts to establish a matrix on Microsoft Excel. 401 actors were identified and included. The names of the actors were placed in corresponding order along the first column and first row of the matrix. Every cell in the matrix had either a "0" to represent no direct communication from the row actor to the column actor or a "1" to represent direct communication from row actor to column actor. This binary code identified who communicated with whom, and it also established the direction of communication. Some actors could interact directly with one another, whereas others only relayed or received information (but not vice versa). This matrix, known as an adjacency matrix, became the quantified input data for network analysis.

4.1.2 Network Visualization

The first objective was to obtain a visual of the communication network via graph theory. The yEd Graph Editor (version 3.9) converted the binary adjacency matrix into a graph, which displayed the actor titles along the first row and column as nodes and the direct communications as edges with arrowheads to represent directionality. By using the yEd Graph Editor, we were able to select specific nodes of interest and view the edges and nodes directly associated with them.

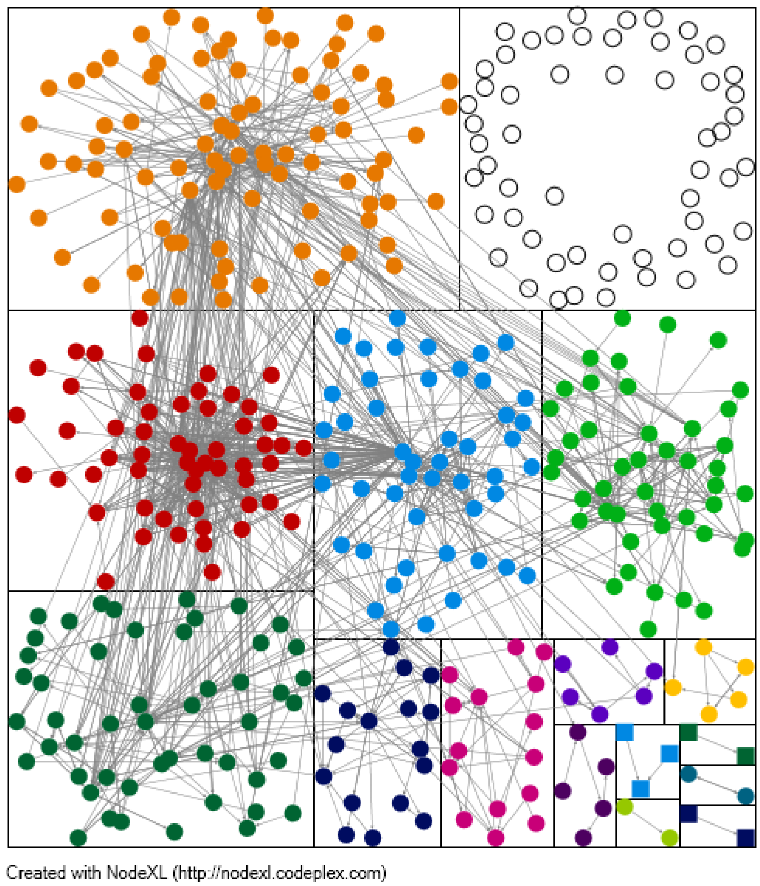


Figure 4.1a – Node XL Clustered Communications Network

In addition to yEd, the NodeXL program was used to group the nodes. NodeXL implemented the Clauset-Newman-Moore Cluster algorithm to assign each node to a specific group. In Figure 4.1a, the groups are differentiated by color and by boxes. The Fruchterman-Reingold algorithm was used to lay out the graph. A more detailed version of this graph with all of the nodes labeled with the organization name can be found in Appendix A.

The cluster algorithm divides the nodes into groups that are highly interconnected with each other. The nodes in the center of each group have the most of these connections. We expect that the center nodes would be responsible for the surrounding nodes in their group. Therefore, we can compare the organizational structure predicted by NodeXL with that of the structures outlined the literature review.

The grouping that is outlined in NodeXL corresponds to color categorizations. The orange group handles the response, the red group handles the threat, and the blue group handles investigation.

4.1.3 Network Analysis

Although the graph provided a significant visualization of the communication network, mathematical algorithms such as the shortest path and the redundancy of subpaths were able to provide an insightful analysis of the network.

We first incorporated betweenness centrality (BC), an algorithm that identified how many times each node was within a specific path in the graph. Through an algorithm in yEd, every node was assigned a weight between 0 and 1 BC to represent their betweenness relative to other nodes. Any node that was independent of all the others was assigned a 0. The nodes with the largest BC values are shown in Table 4.1a. DHS was assigned a 1.00 weight and therefore had the most communications with other actors. The CDC (0.72 BC) and FBI (0.64 BC) had the second and third most BC, which corresponded to their roles in the unified command established by NIMS and further outlined by the *Joint Criminal and Epidemiological Investigation Handbook* (CDC and FBI, 2011). The HHS, the department that oversees the CDC, had a BC of 0.56, and HSEMA, which has responsibility for contacting other agencies in Washington, D.C., the federal government, and private sector actors, had a BC of 0.47, the largest of any local level actor. The National Counterterrorism Center (NCTC), which analyzes possibilities of terrorist threats based on intelligence reports from the DHS, FBI, military, and the DoE, had a 0.33 BC (Graham and Talent, 2008). WRTAC, the fusion center responsible for analyzing the credibility of threats in Washington, D.C., had a 0.21 BC.

Agency	**BC**
DHS	1.00
CDC	0.72
FBI	0.64
HHS	0.56
HSEMA	0.47
NCTC	0.33
DoD	0.32
FEMA	0.32
ARC	0.25
ESF #15	0.24
WRTAC	0.21
NIMS	0.20
EPA	0.20

Table 4.1a: Betweenness Centrality ≥ 0.20

The ARC (0.25 BC) had the highest BC among private sector actors, which corresponds to its significance to the response phase and its work alongside public health agencies. Although ESF #15 and NIMS are plans as opposed to actors, they were included in the analysis because they represent unified efforts by relevant federal, state, and local actors during a bioterrorism attack. ESF #15 focuses on the need for additional support during a response to a crisis, and NIMS is the overarching system for emergency management initiated by the DHS. A source of systematic error in these values is the selection of literature and interviews. Since it was not feasible to contact all relevant actors, details of communications and conference calls came only from chosen documents and the subject-matter experts with whom we spoke. A continued study of the current system could lead to more direct communications that could not be accounted for in this model.

We also recognized that these assigned weights did not directly correspond to overall significance in the response protocols. Programs such as BioWatch (0.11 BC) had relatively small weights because they do not have two-way communication with actors. These systems only provide information and therefore have significantly fewer paths than leading actors. Nevertheless, BioWatch provides essential data for the understanding of pathogen levels in given locations. Additionally, individuals such as the President of the United States (0.06 BC) have a significant role in the establishment of the protocols conducted by relevant actors even though the individuals have few specific actions during the actual CAP.

4.1.3.1 Shortest Paths

Our MATLAB program provided the flexibility to identify the passing of information from detection systems to agencies and local counties as well as communication exchanges between response actors such as the MRC and relevant public health and security actors. These specific paths allowed for a more insightful depiction of the communication network via rich pictures (to be discussed in section 4.1.4). This algorithm provided insight on the relations among different local counties. Although the WRTAC could forward information to the Washington, D.C., DCDOH directly, such information could not be sent immediately to local counties. The WRTAC would engage in a conference call with the FBI and other national security and public health actors to discuss threat credibility before information could be passed beyond Washington, D.C. If the actors deemed the threat credible, the FBI would inform surrounding counties of the impending attack. Shortest paths also outlined how detection systems such as the Autonomous Pathogen Detection System (APDS), Bio-event Advanced Leading Indicator Recognition Technology (BioALIRT), Biohazard Detection System (BDS), Biological Aerosol Sentry and Information System (BASIS), BioStorm, BioSense, BioWatch, Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE), ESSENCE II, NCR Syndromic Surveillance Network, Real-time Outbreak and Disease Surveillance (RODS), and Virtual USA (vUSA) would pass on collected samples or initial data to relevant actors and inform local counties that would have to respond.

The response phase suggested a diverse set of two-way communications. At certain times throughout the phase, the President of the United States has information that is relevant to the MRC, and at other times, the MRC collects data that is of use to the President. The President has discussions with the NCTC, which passes relevant information to HHS, which then passes information along to actors on the ground such as the American Red Cross and then the MRC. However, the MRC conducts both prophylaxis dispensing and field epidemiology. If the MRC were to identify new information, it would communicate with the CDC, who would relay the information to FEMA, who would then inform the President. A number of other examples demonstrated that two-way communication was not always for the same reasons and also had different paths. In order to better understand the common subpaths, or portions of a path that occurred repeatedly, we developed a separate M-file that incorporated this redundancy.

4.1.3.2 Diameter and Redundancy

Upon initial analysis of the shortest paths, we determined that a number of communication exchanges were showing similar subpaths. In order to account for this observation, we wrote an M-file based on Dijkstra's algorithm that could analyze all possible shortest paths in the matrix and identify how many times a particular subpath occurred in other paths. Our M-file then sorted the most common subpaths by number of nodes so that we could specifically identify common chains of communication within the network. The output listed the five most frequent subpaths for each number of nodes (from one to eleven). As expected, the single-node subpaths were consistent with the BC analysis from the graph. The five most frequent occurrences of single-node subpaths were DHS (18,296), CDC (16,835), FBI (16,591), HHS (12,303), and DoD (9,887). DHS has numerous oversight responsibilities throughout the CAP. CDC and FBI lead the investigative effort and are critical members of the unified command. HHS and DoD have great influence in planning procedures as well as in conference calls during an incident. The single-node subpaths are not to be confused with BC. The DoD (0.32 BC) had the seventh highest BC and the fifth most single-node subpaths (9,887). The BC indicated the DoD's placement in the shortest paths between two other actors. However, the single-node subpaths were the number of times the DoD appeared in any (non-cyclical) path between two actors.

The output also provided insight on longer paths of communication that required reasonable extrapolations. The most frequent three-node subpath (2,714 iterations) was the Metropolitan Washington Council of Governments (COG) → Virginia Department of Health Northern Virginia Regional Team (VDH NVRT) → CDC. This subpath implied that certain documents and interviews provided specific communications for particular portions of metropolitan Washington, D.C., but the information was not explicitly a generalization of the communication throughout the region. We could infer from this subpath that the COG could go to any regional public health office within the NCR, and these offices could then report to the CDC. The most frequent five-node subpath (351 iterations) was JAHOC → EOC → WebEOC → Northern Virginia Regional Planner → DoD. Realistically, this subpath makes little sense since WebEOC is not the primary tool for an operations center to forward information to relevant actors. Additionally, the Northern Virginia Regional Planner is not the individual who would report updates from an operations center to the DoD. This “error” occurred because interviews and literature revealed that the regional planner has communications with the DoD on a regular basis and has access to information from WebEOC. The M-File did not account for specific scenarios but only whether or not two actors communicated. We saw the true value of this subpath as the communication between the JAHOC and the DoD. A number of local actors, ranging from D.C. Public Schools to the D.C. Department of General Services, provide information to the JAHOC. This information-gathering capability emphasizes the significance of the JAHOC and EOC, as well as their communications with the DoD and eventually the CDC or other actors.

The JAHOC's relation between local and federal actors became apparent through its frequent appearances in the most common subpaths. The JAHOC appeared in the following frequent subpaths, as seen in Table 4.1b.

Subpath Length (Number of nodes)	Number of Times JAHOC appears in Top 5
1	0
2	0
3	0
4	1
5	1
6	4
7	4
8	2
9	2
10	5
11	5

Table 4.1b: JAHOC's Occurrences in the Most Common Subpaths

Longer subpaths have more interactions with the JAHOC than shorter subpaths. This emphasizes the JAHOC's role in communicating local-level information to a wide range of other actors across jurisdictions and on the state and federal level, as well as with the private sector.

There were a total of eight eleven-node subpaths, and the first five included the five-node subpath JAHOC → EOC → WebEOC → Northern Virginia Regional Planner → HHS. This subpath is not one of the five most frequent five-node subpaths, but the communication from the JAHOC to the HHS was required in order to reach a number of public health actors such as the Office of Attending Physician (OAP) for Congress and the Maryland Emergency Management Agency. Figure 4.1b displays the number of subpaths with each number of nodes (indicated as "Subpath Length" in the chart) from one to eleven.

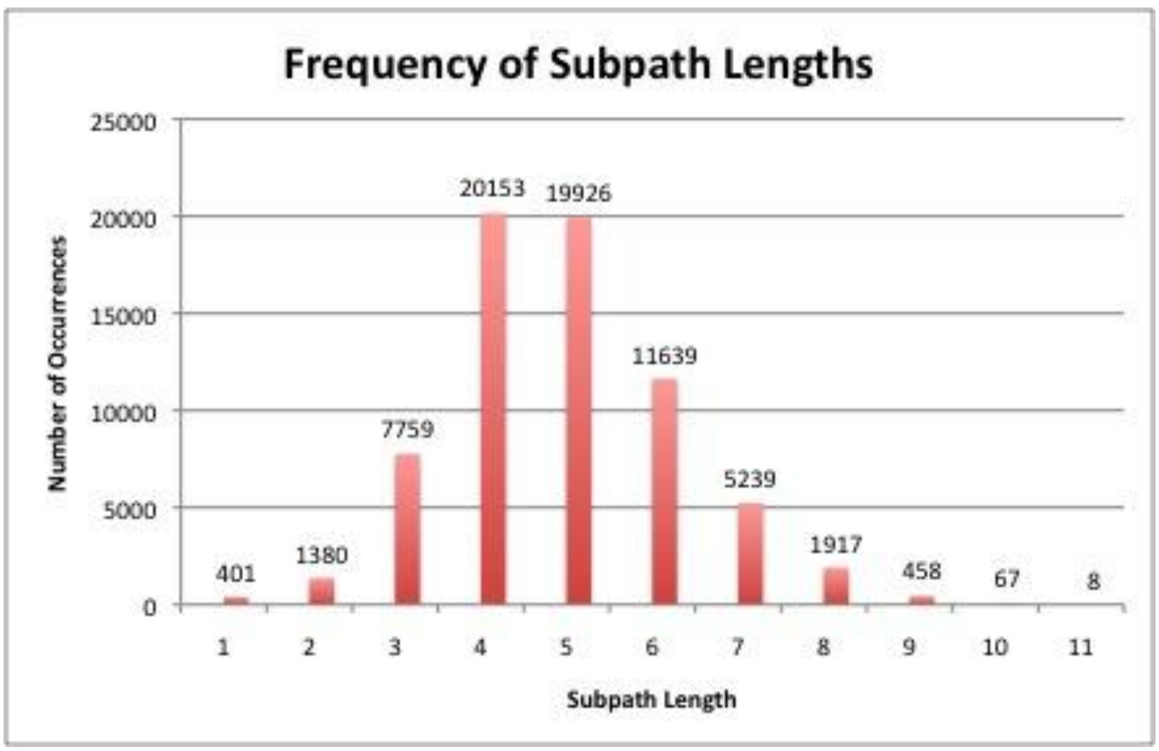


Figure 4.1b - Frequency of n-Node Subpaths

The data indicated that most communications were of 4 or 5 nodes. This result is consistent with the expectation since one would expect information to travel according to the generic subpath: Local Actor A→ State Actor A→ Federal Actor → State Actor B→ Local Actor B (5 nodes).

4.2 Rich Pictures

As we analyzed the compiled information from our literature review and interviews, we developed an overarching rich picture, shown in Figure 4.2a, which is a depiction of the response protocols. This picture categorized the protocols into “Detection and Investigation,” “Decision-Making,” and “Response.” All three categories showed a linear progression of events and actions taken by local, state, federal, and private actors. The picture provides a broad yet insightful view of the relevant actors during the CAP and during the establishment of PODs and follow-up investigations and prophylaxis distribution. This rich picture, and the additional rich pictures discussed later in this section, is informal, as hand-drawn figures are acceptable for this step of the methodology.

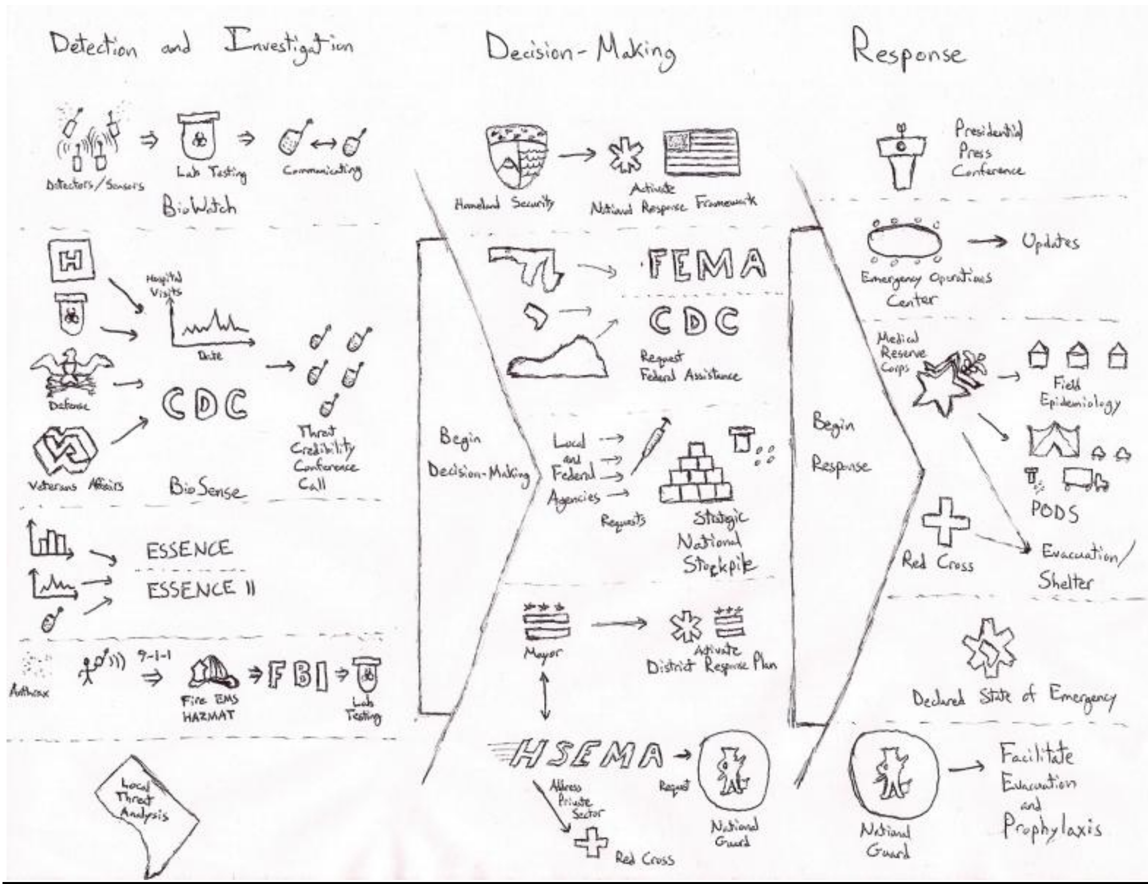


Figure 4.2a – Response Protocols

The actions and communications account for a witness identifying a potential threat and established detection systems reporting spikes in symptoms or pathogens in the environment. Confirmatory testing via LRN labs and Lawrence Livermore, along with threat credibility conference calls, lead to a decision-making phase. At this time, Washington, D.C., and state governments can determine the need for federal assistance, local and federal actors can request prophylaxis from the SNS, and departments such as DHS can implement pre-written response plans. These decisions formally end the CAP, and construction of PODs can begin with the assistance of local health department employees, the MRC, the National Guard, and/or private sector actors such as the

American Red Cross. The MRC's continuous field epidemiology and EOC updates maintain a steady investigation of any further threat. As agencies make specific information available to the public, the president also provides the most suitable public address under the current circumstances.

Since the response protocols incorporated a number of actions within one picture, we developed additional rich pictures to provide more information on some of the specific actions that take place. We developed pictures for the detection, investigation, and response based upon actions identifiable through literature, interviews, and our analysis. The "Detection Systems" picture, Figure 4.2b, indicates the actors that receive information from several detection systems early in the CAP. The DHS, FBI, and CDC receive initial updates from a wide variety of technological and syndromic surveillance systems, and information-sharing networks also facilitate the compilation of data from specific areas of the NCR.

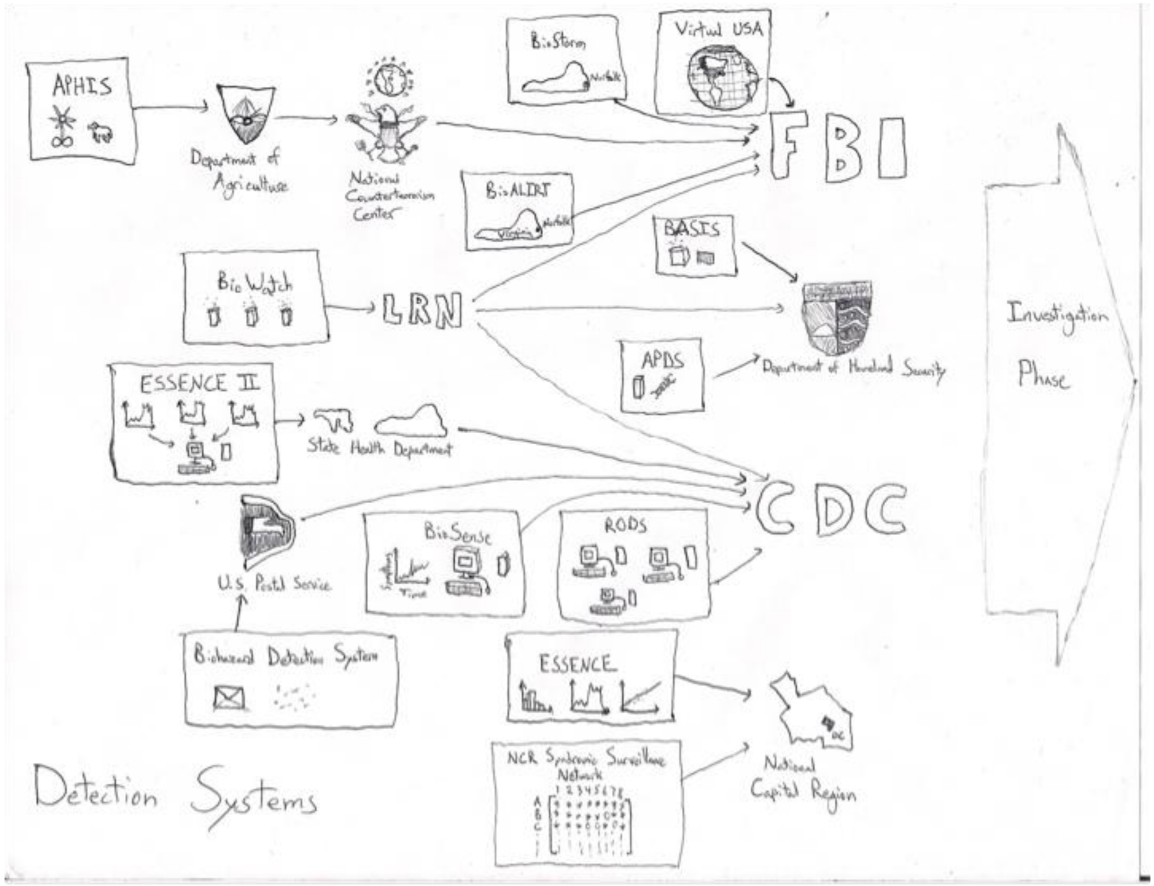


Figure 4.2b – Detection Systems

According to the "Investigation" picture, Figure 4.2c, the initial report of covert bioterrorism can lead to three distinct outcomes. After the first threat assessment conference call, attended by local public health and law enforcement, the LRN, FBI and its local level associates, and the local fusion center, the attendees classify the incident as "No Risk," "Possible Bioterrorism Risk," or "Likely Bioterrorism Risk." A "No Risk" classification results in a prophylaxis response driven by public health. "Possible Bioterrorism Risk" requires additional investigation, which causes the FBI to run a criminal investigation while public health runs an epidemiological investigation. In the event of a "Likely Bioterrorism Risk," the FBI initiates a "WMD Threat Credibility

Evaluation" conference call along with the CDC, local FBI and public health. This conference call leads to a joint investigation establishing unified command between the FBI/law enforcement and public health actors. In addition, the FBI opens a case file and can choose to establish a JOC.

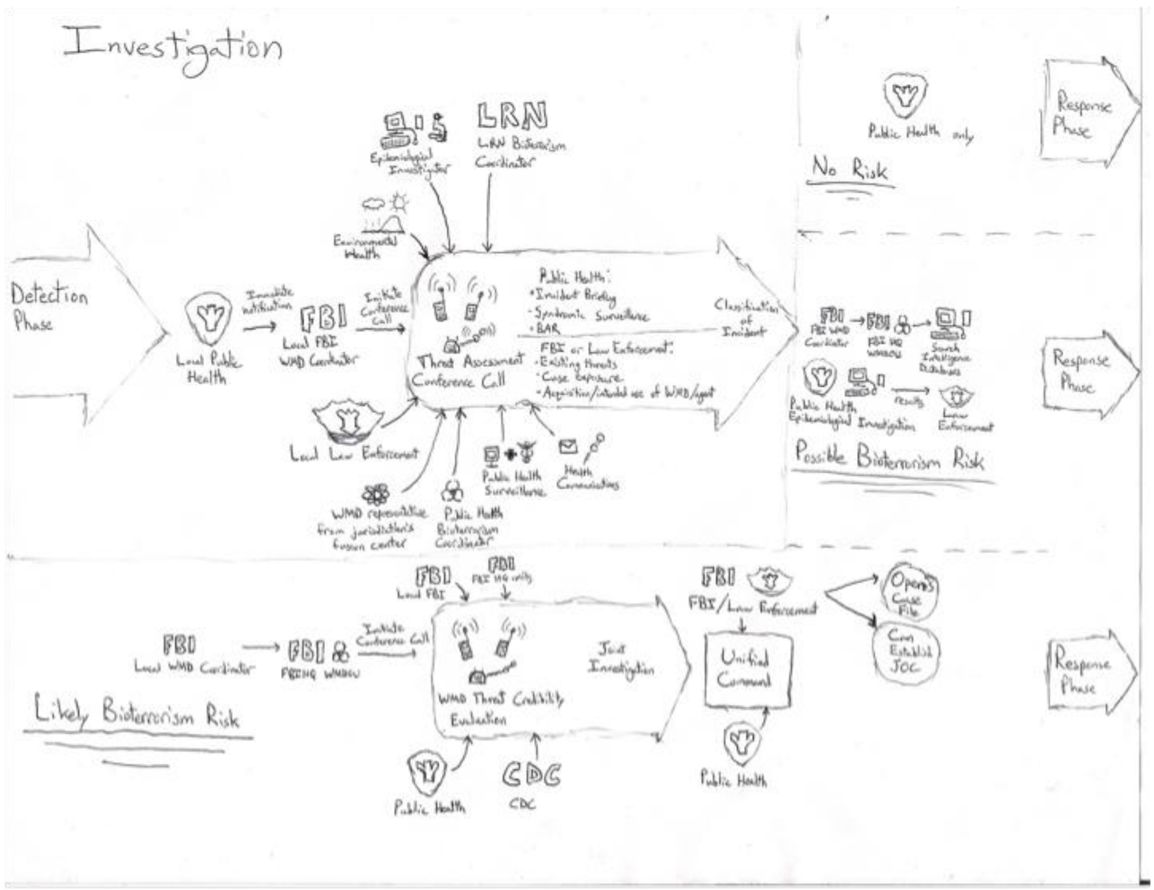


Figure 4.2c – Investigation

Upon making a decision, the Response picture, Figure 4.2d, provides a case study of POD set-up and prophylaxis distribution. The Montgomery County Health Department requests assistance via the Maryland Department of Health and Mental Hygiene (MD DHMH), who runs through the legal procedures to forward the request to the CDC. Upon approval, the CDC informs the county of assistance. The county can establish coordination with Johns Hopkins for further assistance and information exchange. Between 1 and 24 hours after the CDC's acceptance of the request, county public health staff, the MRC, and additional volunteers set up the PODs. If necessary, the American Red Cross and, via a request from HSEMA, the D.C. National Guard can also help establish the PODs. Individuals can receive prophylaxis through a drive-up, walk-in, or delivery to heads of household. During this process, the MRC would conduct field epidemiology, or counties with no MRC would conduct the epidemiology with assistance from DHMH, and any new information is transmitted to the CDC, who then forwards the updates to the EPA, LRN, FBI WMD Coordinator, and FEMA. Through FEMA, the president can receive vital updates from the scene.

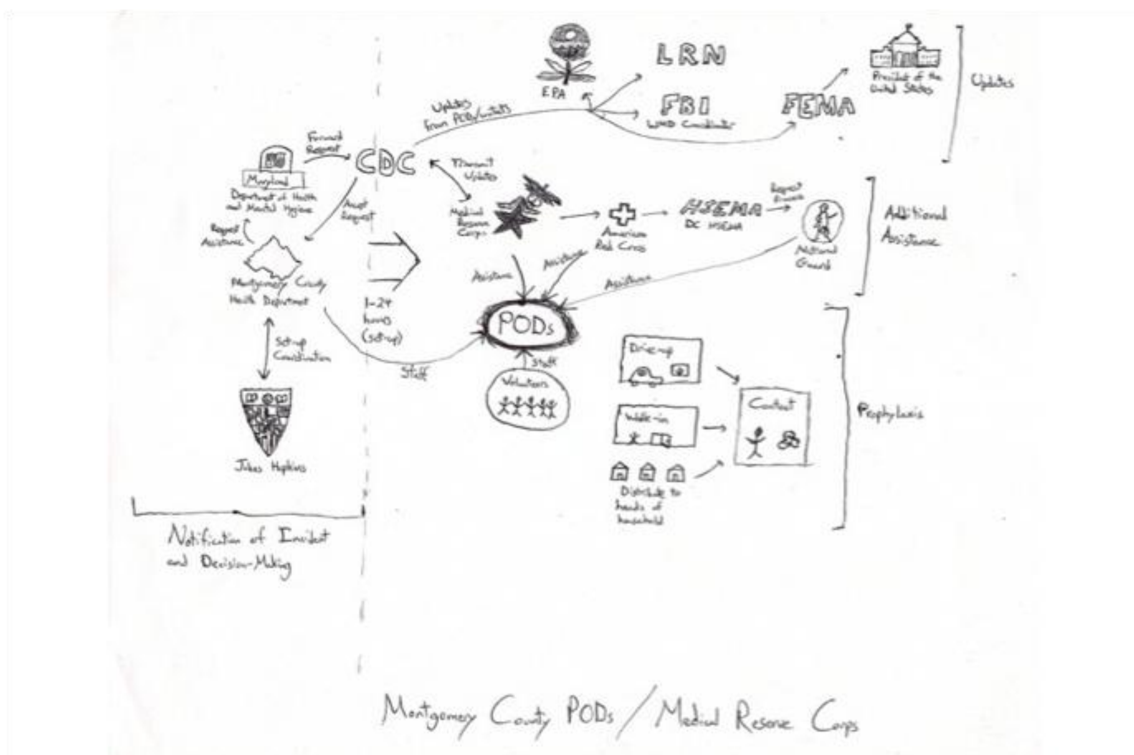


Figure 4.2d – Response

4.3 Root Definitions

As stated in Chapter 3, our root definitions essentially spell out the main goals of the system we studied. We defined one overlying goal of the entire system, with three subsystems that had to be analyzed individually. The root definitions we determined were to (1) save lives, (1a) maintain proper surveillance and intelligence, (1b) have proper decision-making and contain the physical threat of the anthrax, and (1c) control and manage the public. Each root definition was detailed through CATWOE, and we constructed a model of interaction for each definition. These models of interaction are described in Section 4.5.

4.4 Simulation Results

Our extensive work of using simulation programs throughout our research has given us a wealth of information to use in forming our recommendations for feasible and desirable changes in the response to an aerosolized anthrax attack. Our anthrax incidence model written in the Ruby programming language as well as the HYSPLIT program were used to generate simulation results given a particular area and its population to detect how many incidents would generate over the process of a five day simulation.

4.4.1 Anthrax Dispersion Results from HYSPLIT

We conducted four separate sets of simulations, each with their own set of meteorological data. These simulations calculated the anthrax dispersion for the first 120 hours after the anthrax release. Each set of data had its own pattern, and this affected the anthrax dispersion across each of the simulations. Here we discuss these particular patterns.

4.4.1.1 9am on January 1, 2010

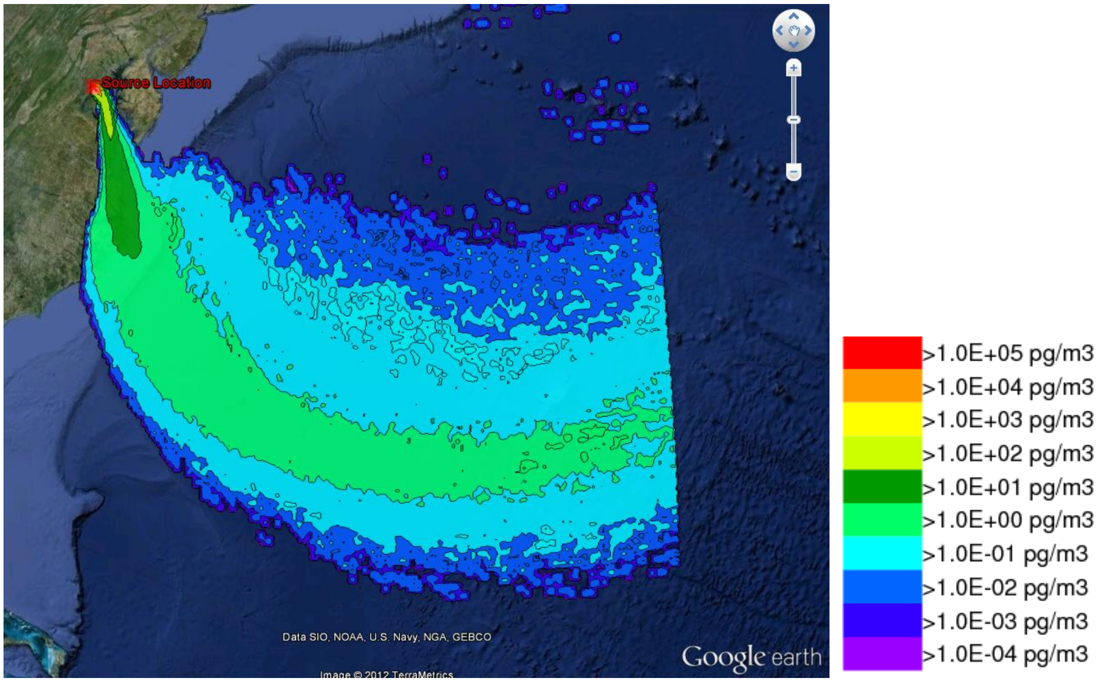


Figure 4.4a - 10 kg anthrax dispersion over first 5 days

The anthrax dispersion of January was fairly standard across its four levels of concentration. As shown in Figure 4.4a, as the anthrax would spread, it would simply go south along the east coast. Most of the anthrax would travel south, infecting residents from Washington, D.C., to North Carolina, and increasing the amount of anthrax would simply increase the amount of infections.

There was a curious development, though, in that some of the spores would actually travel north and create germinations in Massachusetts. This occurred during the heaviest concentration of 10 kilograms. We believe this could be incorrectly interpreted as a second anthrax release, and this led us to consider a false positive in detecting spores in areas far-off from the release area. This is highly important to consider depending on the amount of anthrax released in a given test.

4.4.1.2 9am on June 9, 2010

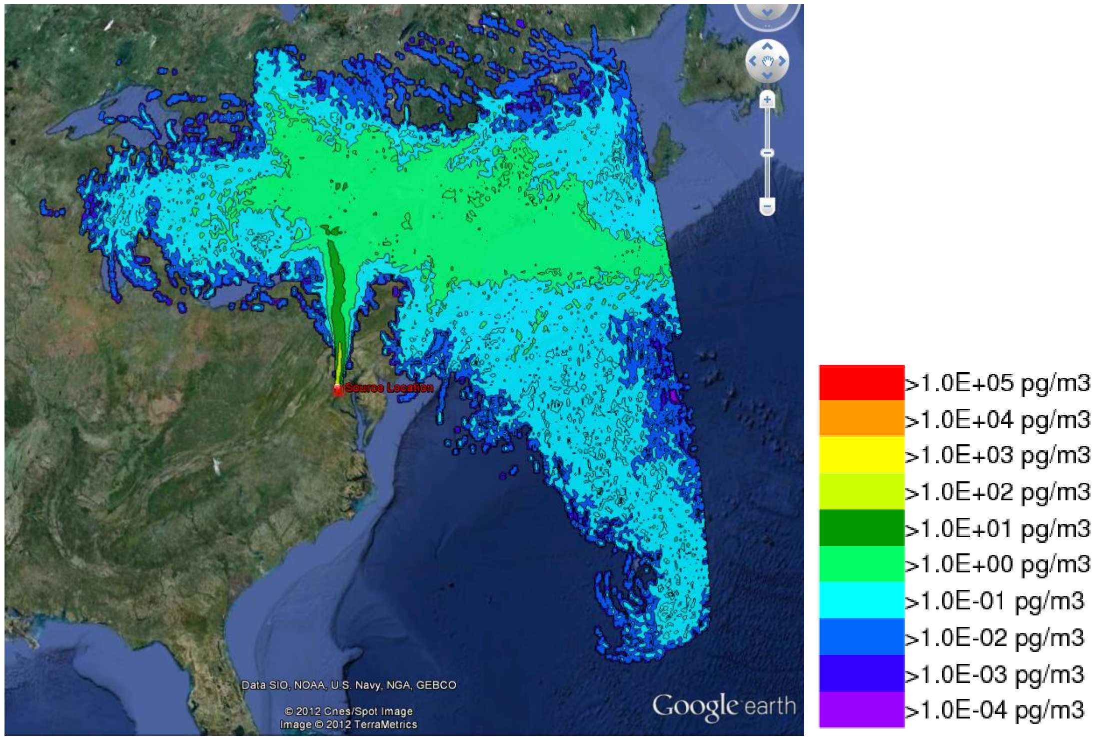


Figure 4.4b - 10 kg anthrax dispersion over first 5 days

The second dispersion data set we studied, shown in Figure 4.4b, went in the opposite direction from the first. Rather than spores traveling south along the coast, these traveled north and had a wide development, reaching as far as Wisconsin and Maine.

The locations where we observed high concentrations had certain tendencies. While Wisconsin and Michigan as well as other areas surrounding the Great Lakes did experience germinations of spores in their areas, there was certainly a heavier effect along the coastline. The spores traveled up through Pennsylvania and germinated in practically every area of New England. The highest concentrations were in relatively small areas near the release point. This wide spread was expected, considering that over three million people were determined sick in the simulation. This simulation quantitatively depicts the range and devastation of such an attack.

4.4.1.3 2am on July 2, 2010

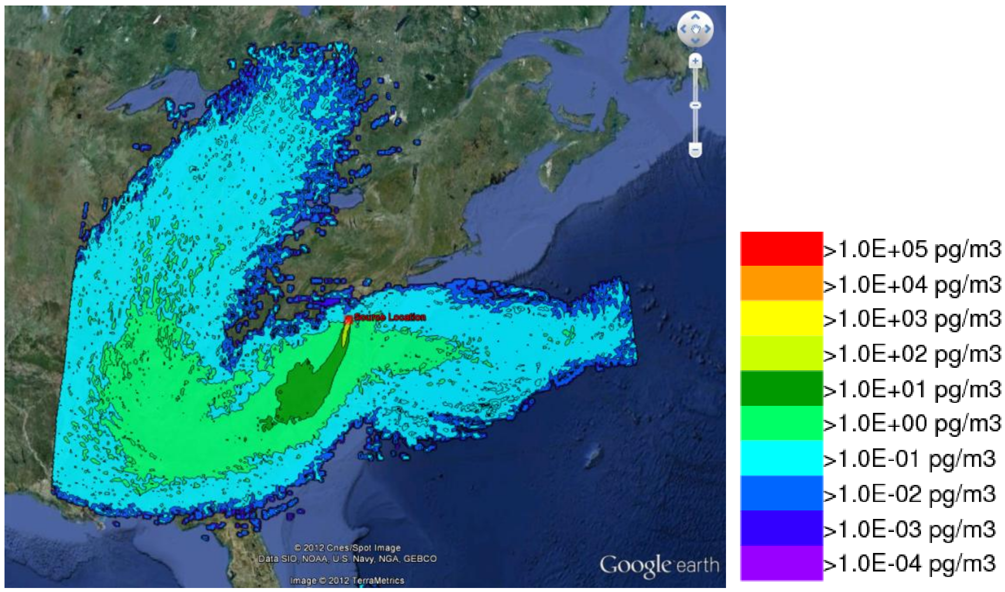


Figure 4.4c - 10 kg anthrax dispersion over first 5 days

This set of simulations had the largest range compared to the others in our analysis. As shown in Figure 4.4c, a swirl pattern was created from this meteorological data, and it caused the anthrax spores to spread directly inland from Washington, D.C. There was a large amount of germinations in the Carolinas, and it decreased as the dispersion tended further south before the swirl would turn the spores back up north toward the Great Lakes. Essentially, the pattern created a "box" range with the borders of just past the Mississippi River, the Great Lakes, the East Coast, and the Gulf of Mexico. At the heaviest concentration of 10 kilograms, the simulation counted eight million cases of illness, and there was a wide geographic area to account for these.

4.4.1.4 9am on September 1, 2010

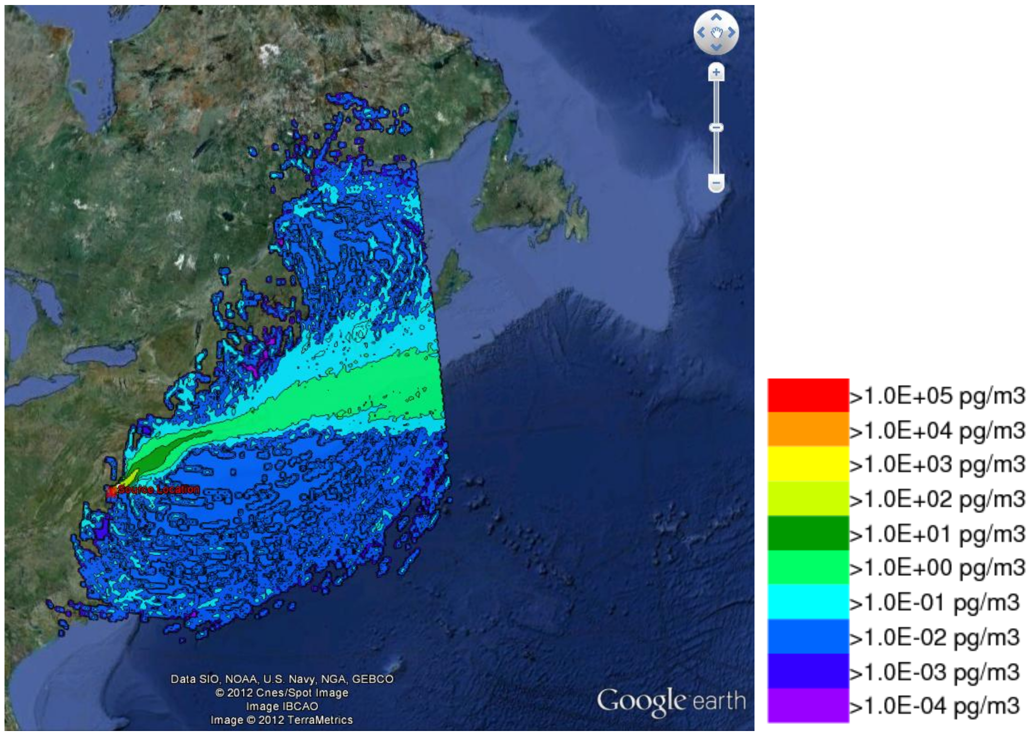


Figure 4.4d - 10 kg anthrax dispersion over first 5 days

This set of simulations created a set of data similar to the first set (Figure 4.4a), but the dispersion had a wider range all along the East Coast. As shown in Figure 4.4d, the spores travelled as far south as Georgia and as far north as New England. While the second set (Figure 4.4b) displayed a similar inward spread, this set consistently stayed along the coastline.

4.4.2 Anthrax Incidence Results

We generated numerous results from our anthrax incidence program. As we discussed earlier, our focus was on four specific release times (i.e. year, month, day, hour when anthrax is released) throughout the year for which we were going to generate results in our simulation. The specific times we picked were during January, June, July, and September. Each formed a different meteorological pattern for us to explore and test to generate varying results. These patterns will be discussed later.

For our Incidence Model, we tested each of the four release times with a differing amount of anthrax, namely 0.01, 0.1, 1 and 10 kilograms, to get four separate results from each specific chosen time. See Appendix D for more information on the parameters held constant and varied for the simulations. Across these sixteen separate simulations, our Incidence Model generated the following results (these results are limited to the simulation, month, release amount, and total sick, as our simulations have given us a multitude of data that includes latitude and longitude for everyone incident as well):

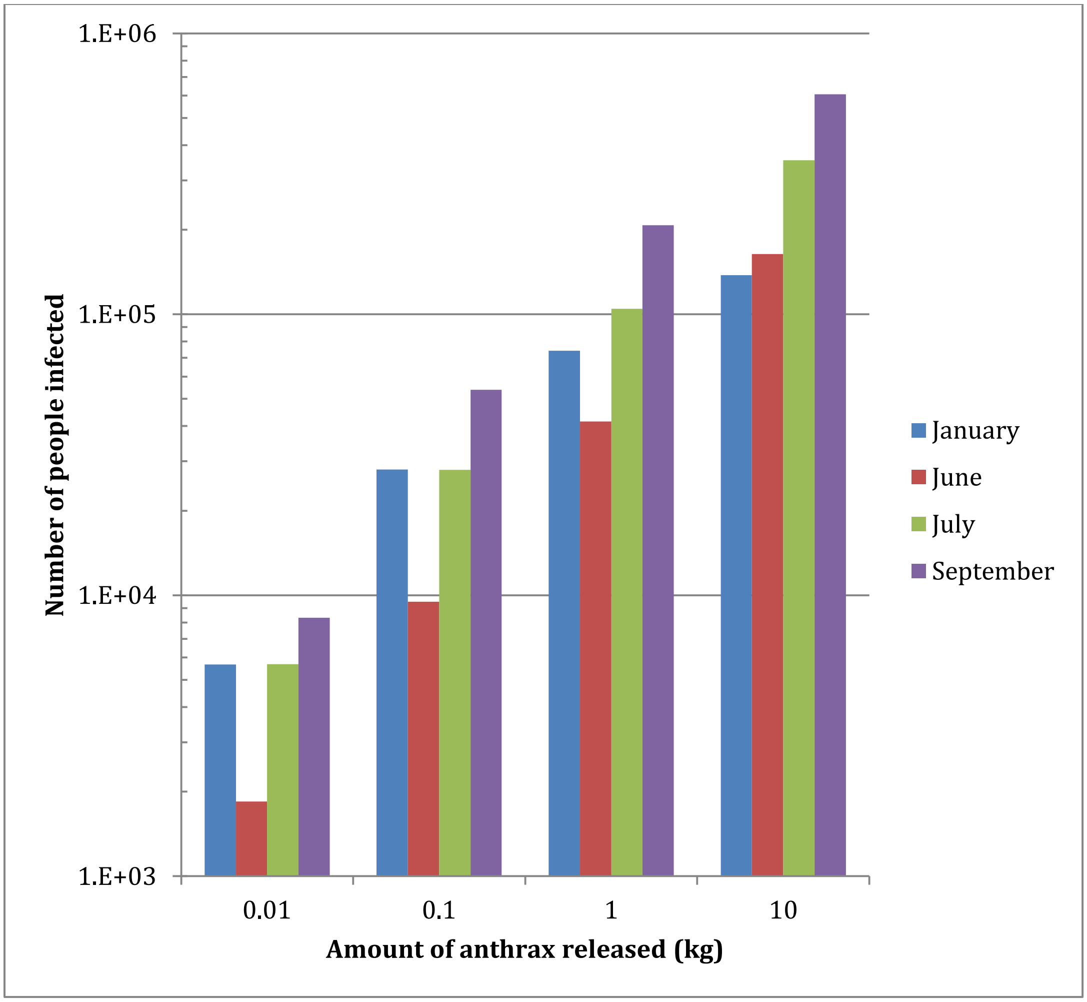


Figure 4.4e – Number of people infected by 120 hours

Figure 4.4e shows the number of people infected in the first 5 days following an anthrax release for each of the 16 simulations. As expected, a greater quantity of anthrax released results in a higher incidence of anthrax disease. Note that infected individuals may not show immediate symptoms in a real-world scenario. Figure 4.4f is a similar graph, except it shows the total number of people infected with anthrax as time approaches infinity assuming no prophylaxis is administered. Comparing the two figures shows that over half of the incidence of anthrax typically occurs more than five days after the initial anthrax release.

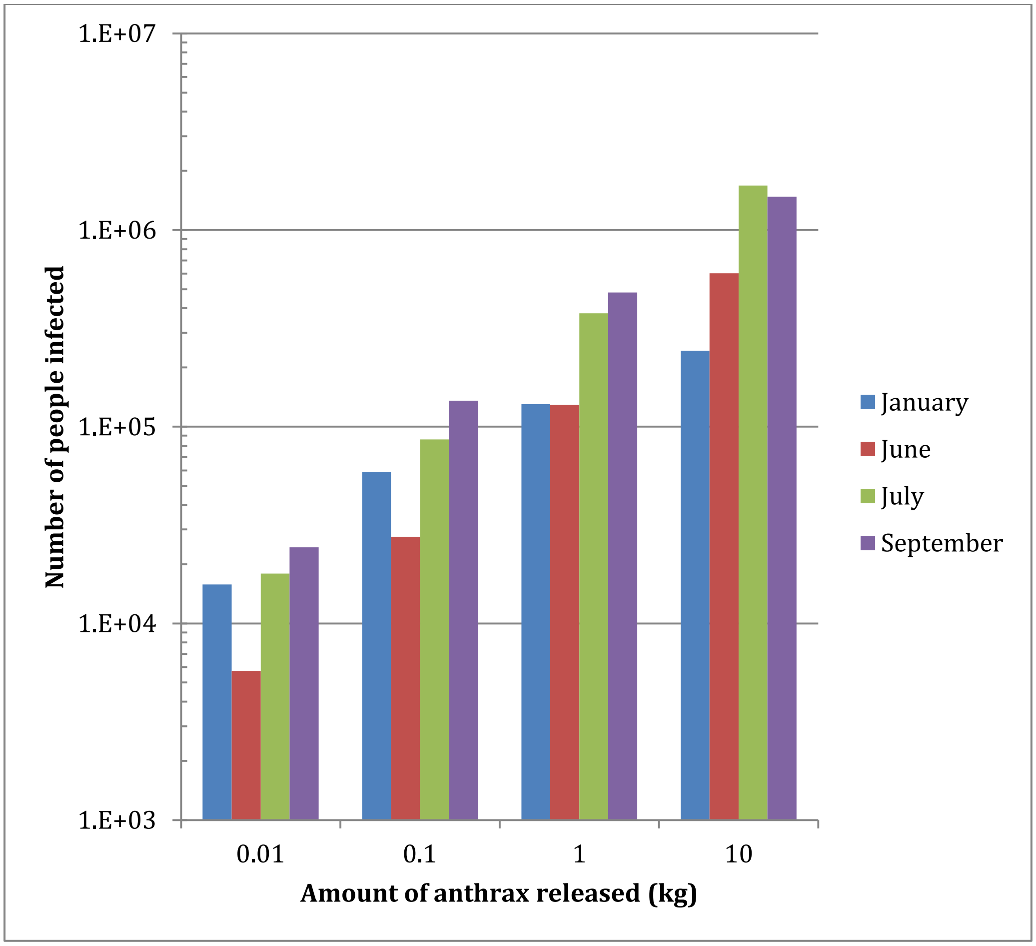


Figure 4.4f - Total people infected by time → infinity

To account for the stochastic component of the algorithm used in the anthrax incidence model, each of the 16 simulations were run five times, and the average values of the results were used to create Figures 4.4e and 4.4f. The widths of the 90% confidence intervals were less than 1.4% of the sample average for all of the simulations. This suggests that the use of random numbers in the algorithm does not strongly affect the results. The larger releases of anthrax tend to have smaller margins of error, which makes sense since the statistically random numbers balance out as more people get sick.

4.4.3 Comparison of Simulation Results with Wilkening Research

Although our simulations gave us extensive results, we sought to compare them with similar research to see how close our studies matched their own. We chose to compare our simulations to the results of the "Uncertainties Associated with Atmospheric Anthrax Attacks" paper done by Wilkening, and found immediately that there were major differences between our model and theirs. First off, Wilkening used a system known as ID50, which means that there is a 50% chance of someone getting infected as a function of how much is inhaled. We, on the other hand, tested each individual with a percentage chance of him or her getting sick to give us more specific results on this broadened scale.

The parameters we relied on in our simulation are different as well. We used a constant breathing rate of 1.8 m^3/hour, but in comparison, Wilkening considered breathing rate as a function of time of day. This led to our value being about three times as much as their average, and therefore we expected to get higher numbers in comparison to theirs. We used the 2000 census data, whereas Wilkening used Landscan data, on population density.

Another difference we encountered was in regards to the spores per gram. Wilkening considered 10^{11} spores/gram, while we considered $1.43\text{x}10^{12}$ spores/gram, meaning that our 0.1 kg release should be the simulation compared to their 1 kg release. Our meteorology data differs as well, using vastly different years. Wilkening used 1990 in their studies while we used 2010 data. But one other factor that could affect our result comparison is indoor reduction factor, something that only Wilkening used. The indoor reduction factor reduces the amount of anthrax inhaled by a factor of about 0.6, which we believe accounts for the fact that some people will be outside. Because we did not use something similar in our studies, we found that this too would contribute greatly to differences in our data.

4.4.4 Case Study of Simulation #7

June 9, 9am (2010) 1

As an example of the results of the simulation model, simulation #7 is analyzed in more detail. In this simulation, 1 kg of anthrax was released on June 9 at 9 AM. This simulation was chosen since it has a medium-sized anthrax release, as well as a particularly interesting dispersion pattern (as shown in Figure 4.4b) where the anthrax leaves the United States before returning to the Northeast and Midwest United States.

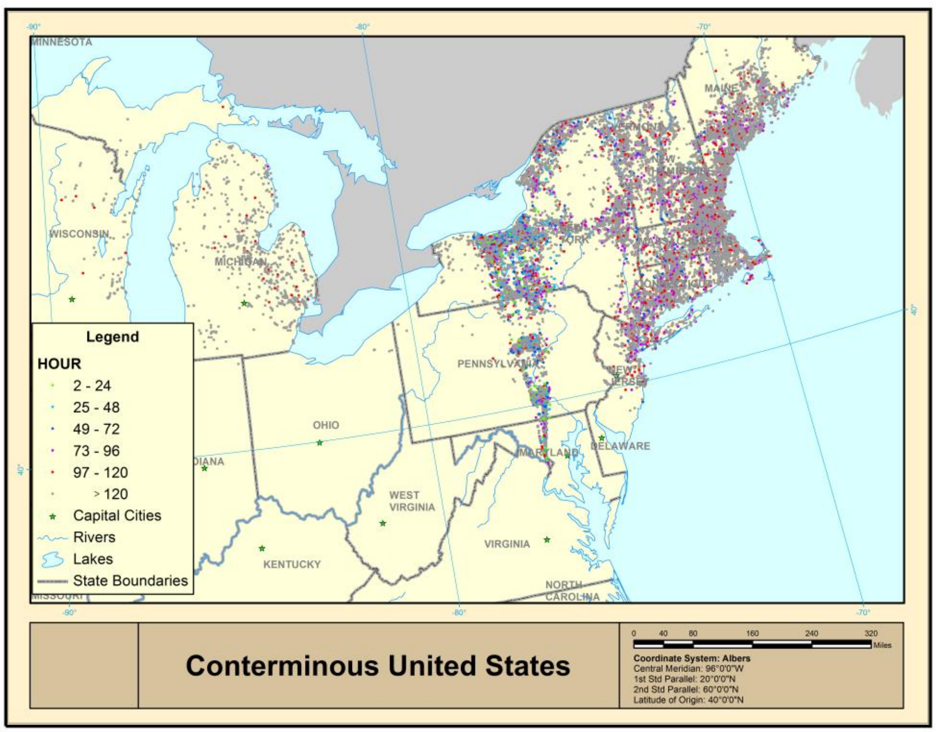


Figure 4.4g – Simulation 7 plot of incidence vs. time, including t > 5 days

In Figure 4.4g, each point represents a person infected by anthrax. The points are color coded to represent the time that the infection occurred. Since no more than one person per 30"x30" grid cell is plotted, not every person is shown, but the general distribution can still be inferred. The person plotted in the grid cell is randomly chosen. The majority of the points on this plot are gray; signifying that most of people do not become infected with anthrax until at least five days after the anthrax is released. This incubation period remains true even within the area of initial release. In this case, 67.9% of the 129,277 people infected in the U.S. during this simulation were infected more than five days after the release. Since the anthrax dispersion was only simulated for five days, this percentage might be artificially low because the anthrax was still present in the atmosphere after the five days.

To make the results relevant to immediate response easier to visualize, Figure 4.4h shows the same plot as Figure 4.4g excluding the people infected after five days. In this plot, the people near the release (north of Maryland) were the first population to be infected while more people in that region continuously became infected as time passed.

Another important observation from the simulation is that although the anthrax is released in Washington, D.C., a large area of the U.S. is affected. Since not everyone in the high density regions is displayed, this figure is slightly misleading. In fact, 22% of the people infected are inside the beltway region of DC.

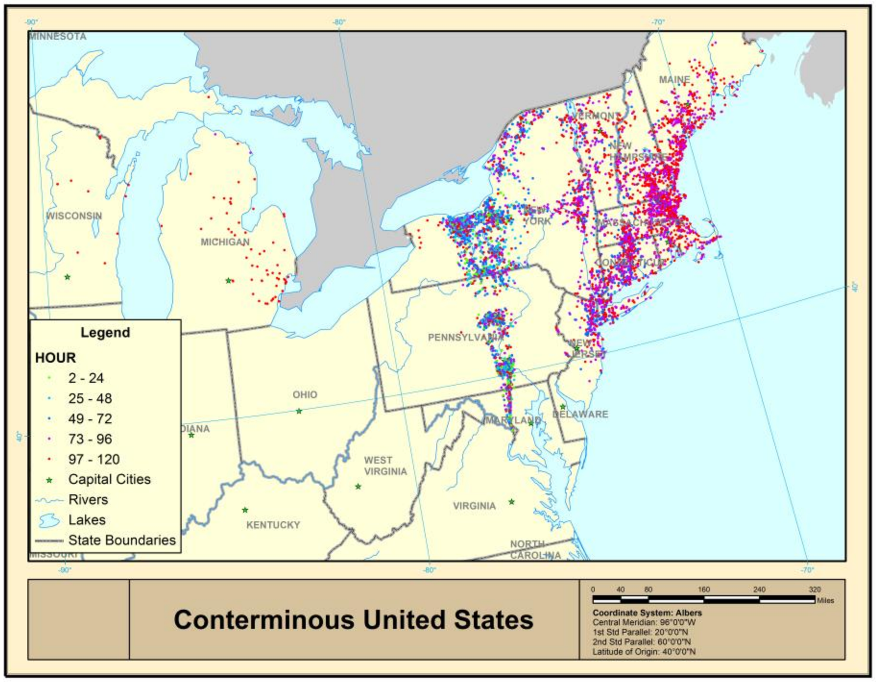


Figure 4.4h – Simulation 7 plot of incidence vs. time for first 5 days

4.5 Models of Interaction

One model was dedicated to each root definition. The models were developed via Microsoft Project using information from the rich pictures. Figure 4.5a is an overview of the models of interaction. The overall model we constructed is entitled "Model 1" and refers to our number one root definition - saving lives. This model had to be completed subsequent to the other three models, as it utilized their elapsed time information. Ultimately, Model 1 compared the overall timeliness of the three submodels with the number of people who could potentially become sick over time, as calculated with our computer simulations. Model 1a corresponded to Root Definition 1a, as it displayed the surveillance and intelligence surrounding an attack. It detailed the surveillance, release, and detection of anthrax. This model ended with authorities investigating and possibly locating the source of the attack (depending on its nature) as well as positively confirming the use of anthrax. Model 1b charted Root Definition 1b, the decision-making process and containing the threat of the released substance. It followed the decision-making, management, and containment of the threat and ended with the proper authorities making decisions regarding cleanup and public management. A likely end result of this model would be the initiation of ESFs. Model 1c corresponded to Root Definition 1c, managing the public. After a decision was made in Model 1b with regards to the public, this decision would need to be executed. Ordinarily, this could be the actual formation and use of PODs. Figure 4.5a below corresponds to the relationship among the three submodels.

Each model was constructed with multiple pathways of tasks, displayed in boxes on a Gantt chart. Each task also listed CATWOE information for our critical path analysis. As our graph theory analysis indicated, a large amount of time during the response would be dedicated to lines of communication. Communication likely to take significant time was included in the models. The models appear in Appendix C.

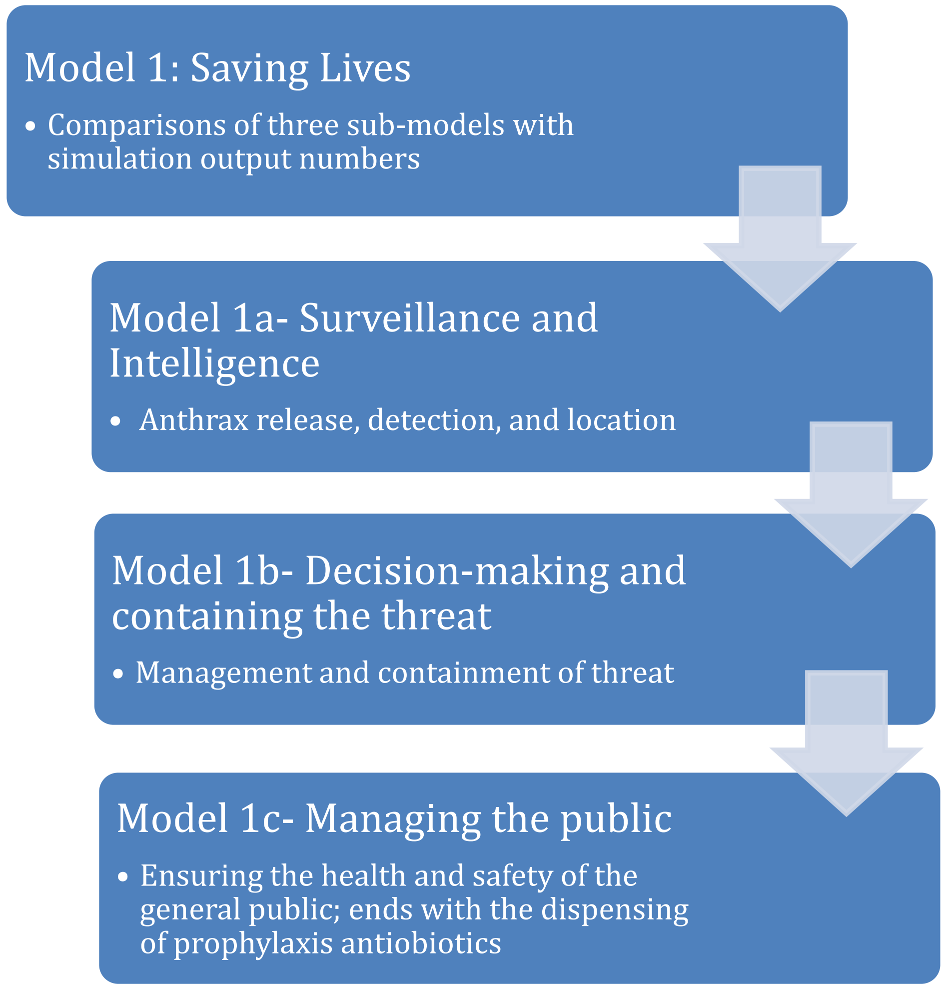


Figure 4.5a: Flow of the models of interaction

4.5.1 Model 1a- Surveillance and intelligence

Although all of the information provided for constructing the models was taken from our rich pictures, most of the information on this model specifically came from the rich picture sources of ESF #8, our interviews, and the ConOps. This model began with the task "Release." This task could represent any scenario of aerosolized anthrax release but was then differentiated into three scenarios: direct observation, incubation, and recognition via BioWatch.

The start time for direct observation remained at the same time as the release, t=0, because witnesses would watch the release as it happened. The time frames for incubation and BioWatch were taken from rich picture information. Primarily, the ConOps and our interviews determined a path for direct observation. Similarly, the timeframes for each task were largely taken from interview information.

Following the incubation of the anthrax and the onset of symptoms in contacts, our models indicated two pathways: the astute physician and syndromic surveillance, the latter specifically being ESSENCE recognition. The path following the astute physician to the confirmation of anthrax in a patient and the subsequent contact interview that marked the end of Model 1a. The ESSENCE recognition path followed protocol largely spelled out in our literature review.

The BioWatch path followed several descriptions of the program that we found in our literature review and from our interviews. It should be noted that all of these pathways were written in scenarios that were described as normal pathways; the timeframes we constructed were not arbitrary but were by no means certitude. Chapter 2 details how programs such as BioWatch have varied in their ability to positively recognize anthrax, and how response has varied in the past.

4.5.2 Model 1b- Decision-making and containing the threat

Model 1b began while the tasks of Model 1a were occurring. The two start points of this model were direct observation and the declaration of a BAR. The start point of incubation was omitted in this model because of its unpredictability with regards to timing and the dependency of response protocols on case-by-case situations (determined by the number of people affected, etc.).

The two pathways in Model 1b largely mirrored each other, with the exception of timing differences. As with Model 1a, the pathways and timing were taken from our rich pictures, especially the ConOps. There was a large amount of overlap with the tasks in this model, which later played a part in our critical path analysis.

4.5.3 Model 1c- Managing the public

This model only followed one scenario and could apply to all of the scenarios laid out in Model 1a. The starting task for this model was the initiation of NIMS and ESF #8, at time t=0. This model was largely based off of ESF #8 and featured specific information surrounding PODs taken from our interviews. The model detailed many communication lines that were outlined in ESF #8 as well as potential actions that could be taken—but were not required—following the initiation of this ESF. Model 1c ended with the functioning of PODs but did not detail when each POD would close, as this time would vary greatly.

4.5.4 Model 1- Comparison of models with simulations

Model 1 detailed how many lives could potentially be saved, as shown in Table 4.5 and Figure 4.5b, by comparing timing information from our three submodels with that of our computer simulations. We used the aforementioned data from our computer simulations and created a new program to detail the hourly number of people who would be exposed to enough anthrax to make them sick, roughly corresponding with what is considered “inside the Beltway”.

Time (hours)	Scenario	Task
0.75	Direct Observation	HEPRA Alerted
3.01	Direct Observation	Decision of Response
13.15	Direct Observation	ESF Initiated
28	BioWatch	HEPRA Alerted
33.85	BioWatch	Decision of Response
36.5	BioWatch	ESF Initiated
40.11	Direct Observation	PODs Functional
58.2	BioWatch	PODs Functional
115	Astute Physician	Decision of Response
120	Syndromic Surveillance	HEPRA Alerted
135	Astute Physician	PODs Functional
141	Syndromic Surveillance	PODs Functional

Table 4.5 - June 6, release of 1 kg

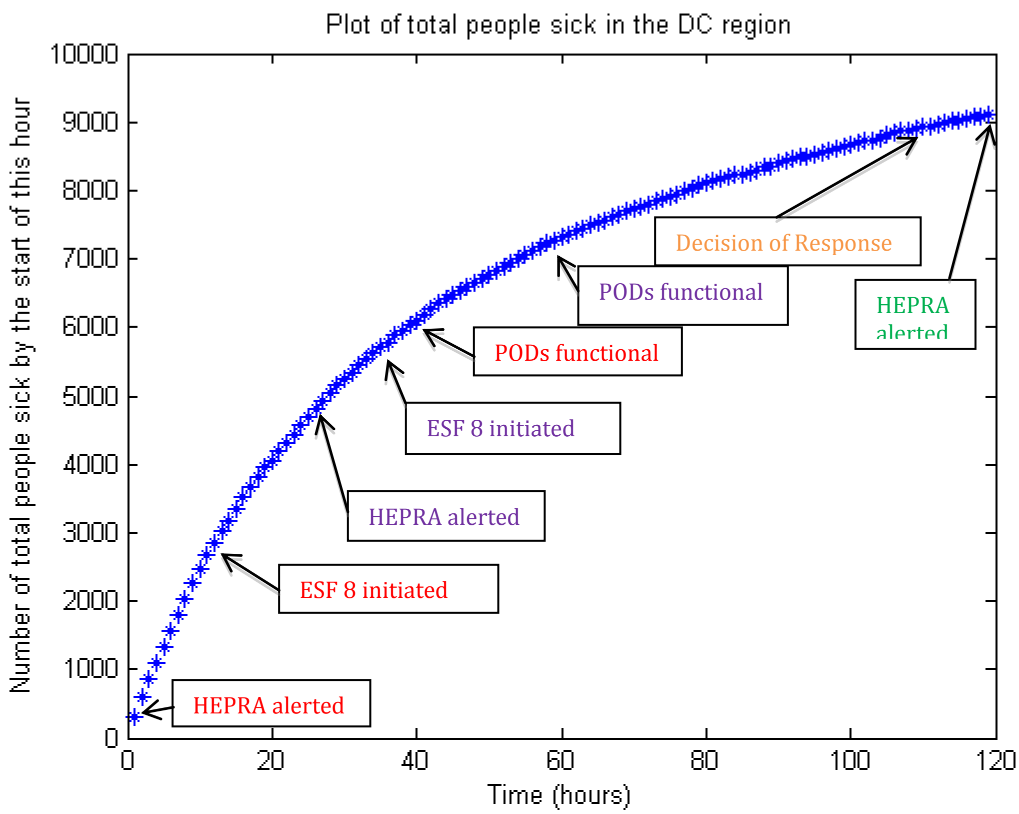


Figure 4.5b - Total number of people infected by 120 hours = 9109 people

Key:
Direct Observation, BioWatch, Astute Physician, Syndromic Surveillance

We followed the scenarios presented in Model 1a to find the proper timing numbers. Using the Gantt charts, we determined for each scenario the timing from release of aerosolized anthrax to the commencement of public distribution of prophylaxis antibiotics. Milestone information, such as when HEPRA was alerted of an attack, was compared with data from the Total Sick Hourly model, in Model 1. Based on the Total Sick Hourly simulation of a 1 kg release of anthrax in June, Model 1 displayed in one graph the various timings of the milestones. For example, in the direct observation scenario, HEPRA would be alerted at 0.75 hours, ESF #8 would be initiated at 13.15 hours, and the PODs would be functional by 40.11 hours. For a BioWatch scenario, HEPRA would be alerted at 28 hours, and the PODS would be functional by 58.2 hours. For the astute physician scenario, PODs would not be functional until 135 hours had elapsed since release. Most tellingly, a syndromic surveillance scenario would not allow PODs to be functional until 141 hours had elapsed.

These numbers clearly indicated that improvements were necessary to the current system. This led us into our next steps, determining the critical paths and secondary discrepancies.

We found the critical path for each of the following release scenarios: direct observation, confirmation by BioWatch, syndromic surveillance, and the astute physician. In order to find the path, we reorganized the models into chronological Gantt charts by scenario. Each of the new four models followed a path from release to the formation of PODs. Using Microsoft Project, we calculated the critical path for each scenario. We then analyzed each task along each critical path to consider the pertinence and necessary duration. This became part of the overall analysis, to be discussed further below.

4.6 Preparing the Idealized Conceptual Model

4.6.1 Overview of Discrepancies Influencing Conceptual Model

After completing our comparisons, we categorized all of the discrepancies we found via direct interviews, literature review, and analysis of our qualitative and quantitative data. We made nine categories: Detect Possible Attack, Investigate and Confirm Attack, Contain Pathogen, Decide How to Respond, Communication Among Actors, Mobilize Responders, Deliver Supplies to PODs, Inform Public, and Open PODs. Each category is discussed in detail below. The purpose of this section is to discuss the discrepancies and problems that delay detection, investigation, and decision-making. Chapter 5 will discuss feasible and desirable changes to overcome these problems. Some references came from our interviews, and because of that, we cannot discuss every detail related to them.

Figure 4.6 – Conceptual Model

4.6.2 Detect Possible Attack

The initial detection of an aerosolized anthrax attack causes some of the most significant delays in the response. The dry filter units are checked every 24 hours, causing a currently unavoidable delay between pathogen release and filter collection. Since these filters and corresponding assay, associated with BioWatch, do not necessarily collect or recognize the pathogen upon release, detection can take as long as two weeks. According to the LA Times, there have been over fifty false positives up to 2008 via BioWatch (Williams 2012). False positives can reduce trust of the detection system in place and can also create hesitation among actors to follow up initial detection if there is strong skepticism about its legitimacy.

The astute physician can also lead to delays. Although the physician would make a judgment based on observation and scientific knowledge, there is still uncertainty until the pathogen is confirmed via lab testing. The CDC and FBI already recognize this uncertainty. Although it is good that they have the awareness, it can also imply that there is hesitation to act in the event of a real anthrax attack because of doubt. Diagnosis of anthrax can be difficult since it can appear similar to the flu with the onset of early symptoms. Furthermore, the astute physician requires the patient to initiate the appointment by choosing to enter the hospital. If the patient believes illness is from something naturally occurring, that individual may not decide to go to the hospital until the anthrax has caused significant harm. All of these hesitations lead to dangerous delays.

Additionally, syndromic surveillance has delays. Since the system is dependent on data input from several geographic locations, delays in data entry will slow the analysis. If an anthrax attack occurs during a flu season, analysis will be more difficult because, as noted in the previous paragraph, anthrax and flu share similar early symptoms.

All of these delays from the various detection methods allow the anthrax pathogen to infect individuals without any initiated response. Since response is time-sensitive, high casualties can result from the very beginning of the response protocols. To initiate quick response, the two most efficient forms of detection are either direct observation or technological surveillance.

4.6.3 Investigate and Confirm Attack

After the initial detection of a pathogen and all associated delays, there are delays from the confirmation process. The definitive diagnostic testing occurs through a certified lab of the LRN, and this process can take hours or days. Also, there are reporting ambiguities in the information sharing process. There does not appear to be a definitive individual who provides the final report. Additionally, lab testing and confirmation from labs not associated with the LRN may face legal boundaries in their reporting of information. Part of the ambiguity and legal questions stems from the lack of oversight. According to the World at Risk report, "no single entity in the executive branch is responsible for overseeing and managing the risks associated with all the high-containment (BSL-3) laboratories operated by the U.S. government, industry, or academia" (Graham and Talent 2008, p. 25). This lack of awareness can lead to information coming from previously unexpected sources that will be doubted despite legitimate scientific claims regarding anthrax confirmation.

The investigation phase includes two simultaneous paths: terrorism and public health. These concurrent investigations can lead to confusion regarding leadership. The unique and significant roles of the FBI, CDC, and local health departments all contribute to the overall investigation, but there can be delays in information sharing. Actors that withhold information citing chain of command may be preventing other actors from taking time-sensitive and completely necessary action. Although unified command is included in NIMS, real-world scenarios can deviate from the plans on paper.

4.6.4 Contain Pathogen

Containment involves understanding the spatio-temporal spread of anthrax. While it is important to develop plume models of the anthrax release, these efforts are not consolidated. DC HEPRA, NOAA, and IMAAC all develop their own plume models without any explicitly stated collaboration. Although discrepancies and uncertainties are important topics of discussion regarding a plume model, having several models of the same anthrax spread can create unnecessary delays in the investigative process. Furthermore, differing models can create confusion in updating the perimeter of the attack, making physical containment difficult for law enforcement and other relevant officials.

4.6.5 Decide How to Respond

The specific roles of certain officials involved in the decision-making process are ambiguous. During conference calls regarding the confirmation of anthrax, the “epidemiological investigator” and “public health surveillance” are considered different actors, just as “environmental health,” “public health bioterrorism coordinator,” and “health communications” are all considered separate (CDC & FBI, 2011). Without clearly defining which agency or individual occupies each role, it can be difficult to distinguish between these titles. Since these titles are not well-established, conference calls can be delayed or lack necessary production because the confusion over roles can take valuable time away from the decision-making.

Specific responsibilities of the President of the United States are also unclear. While the president does not directly alter specific decisions, Homeland Security Presidential Directive #5 enables the president to place the Secretary of the DHS to assume responsibility for managing the incident by utilizing federal resources. This seemingly sudden change in command does not have an explicitly stated set of conditions. Depending on the scenario at hand, the change in command can create delays via briefings and information exchange across different levels of government.

Physicians also have a separate set of delays in deciding how to respond. Not all physicians have formal bioterrorism training, which means that their ability to respond to an attack may not be ideal (Cosgrove et al., 2005). The lack of uniformity in physician training can lead to overloading certain medical centers with patients as there is a limited number of physicians with the appropriate training.

4.6.6 Communication Among Actors

Communication accounts for a number of discrepancies within the response protocols. The vast number of actors involved creates confusion over command and information sharing. Following the first 24 to 48 hours after detection, both state and federal agencies become involved in several capacities according to one of our epidemiologist contacts. This involvement can create competition over turf and resources, as tension within and across actors regarding leadership can create hesitation to work together (Falkenrath, 2010). This hesitation can cause some actors to hide important information from the others. Depending on what the information is, the ensuing delays can cause additional casualties from the anthrax attack. Actors such as the LRN are supposed to standardize information sharing across different detection systems, but they cannot do the job effectively if important facts are withheld. Additionally, the issue of too many communication and information-sharing systems can lead to redundancy. Webfusion, HSIN, and the Regional Incident Command and Coordination System are only three of many technological communication systems in place, and none of them are universal among actors. Furthermore, the redundancy of information comes from the structure of the communication network. The HHS Secretary's Operation Center sends information to four different response branches, and all four of these branches report to the FBI WMD Coordinator. Although the information may not be the same from each of the four branches, this high-volume influx of communications may delay the process and possibly create difficulties in tracking the information.

Information sharing has been a staple of efficiency improvement plans for matters of homeland security since September 11, 2001. However, too many attempts to consolidate that streamlining of information may cause confusion and be self-defeating.

The NRF calls for coordination systems such as the MACS, in which several coordination protocols are taken among a great number of actors. One of these includes the several EOCs, generally provided by certain actors such as DC Fire or DC law enforcement. At the same time, actors such as HSEMA have their own JAHOCs that function when EOCs are not activated. However, once EOCs are activated, the NRCC coordinates with the relevant RRCC, which eventually designates powers to the JFO. The JFHQ-NCR is another source of regular information sharing. Representing HHS is the IRCT, which has a large staff and is also meant for increasing coordination.

Given all of the teams meant for streamlining information, it is very likely that communications and chain of command could be lost among the clutter. There also seems to be no established line of communication for federal agencies to check directly with these operations centers for quick and relevant updates.

Additionally, there appears to be a discrepancy **i**nvolving communication with the private sector. HSEMA is the actor that would likely establish communication with private sector actors following a suspected attack, but HEPRA would likely coordinate the private sector's roles and responsibilities in response to the attack.

4.6.7 Mobilize Responders

A large-scale bioterrorism attack requires a vast number of responders and volunteers to be on scene. Unfortunately, organizing these individuals and giving help to affected people have several points of confusion. The necessary educational requirements for NIMS and ICS are only done once, either at the beginning of the job or whenever a new course is introduced and mandatory. Since there is no established, periodic review of the information from these courses, the responders may not be in an ideal position to help and complete particular tasks if the information is not refreshed. Response protocols and uniformity where applicable are both necessities, and the lack of refreshing responder education can delay the actual actions on the ground. Additionally, a number of responders—professional or volunteer—have other priorities besides their job, such as protecting their family. This inherent truth can lead to responders not being available to help when necessary. Although the reasoning for absence may be sound, the lack of responders will ultimately harm the people in need of assistance at the scene of the attack.

The nature of a bioterrorism attack will also create delays in the transition from detection to response. Since the aerosol cloud of anthrax will spread, the scope of the scene will expand and require more responders to be involved. The possibly overwhelming demand for responders may be too fast for the individuals to mobilize. Furthermore, according to a contact associated with HSEMA, the transition to response is not uniform across jurisdictions, and the overall effort is not completely standardized among agencies and individuals.

4.6.8 Deliver Supplies to PODs

State and federal agencies are put in charge of directly supplying local health departments and certain hospitals with the necessary materials in the event of an aerosolized anthrax attack. While this gives centralized responsibility, it also creates an uncertainty on the part of local actors and first responders on scene regarding how long it would take these actors to replenish these supplies. Since responding to an attack is time-sensitive, any actor involved with this delivery process will need to make sure its role is streamlined to provide effective and quick support. Furthermore, hospitals are not required to follow NIMS protocol, which can result in confusion and delays if the agencies and hospitals are not operating in coordination with one another.

Another issue regarding prophylaxis delivery to PODs is the SNS request process to the CDC. The entire request and consideration process appears to be tailored more to naturally recurring events rather than a terrorist attack, which requires a much faster response than the current procedure can provide. Currently, a local jurisdiction that runs out of its own supplies files a request to the state health department. Upon receiving this request, the state health department seeks the approval and endorsement of the governor. Next, this request is sent to the CDC, where relevant officials decide whether to approve the request or not. If the request is approved, then the CDC activates the SNS and informs the relevant local jurisdiction(s). This entire process seems redundant since it coincides with information sharing among actors and operations centers. Officials in command should already acknowledge the timeliness required in response to bioterrorism and also be aware of the supply and demand for prophylaxis in affected areas.

4.6.9 Inform Public

Informing the public becomes a top priority in a bioterrorism event. The President of the United States has a goal of addressing the public within an hour of a confirmed BAR; however, HEPRA will not have even finished their phone consultation until at least two hours after the confirmation. This discrepancy cannot currently receive proper accommodations because the process of obtaining the necessary information takes longer than the allotted time set by the president. Furthermore, actors abiding by the response protocols will delay information until they are certain that updates are factually correct. Announcements from both government agencies and private sector actors will be vague in comparison to what people may expect or demand because of uncertainty in plume modeling, confirmatory testing, and information sharing regarding SNS delivery and dispensing. By contrast, employees and/or volunteers posting unofficial announcements via social networks such as Twitter or Facebook may provide informative updates, but the information will not be confirmed as true or endorsed by the relevant actor.

4.6.10 Open PODs

As of now the availability of PODs is limited in numerous ways: location, ability to dispense medicine, and inability of some counties (such as Frederick County) to fund an MRC. One ambiguity is the process of planning POD location. Although there are already pre-established locations for POD setup, closed PODs are not taken into account.

Since no current policy requires a hospital or business to report if they are a closed POD, supplies may be ordered for locations that do not need the immediate support. This redundancy may be one reason why request processes for SNS are so lengthy, but the demand for prophylaxis is still high. The system needs a re-routing of prophylaxis delivery.

Currently, there does not appear to be a system for specifically addressing the issue of patient triage, which is associated with the lack of across-the-board standardization in the response process. Interviews and literature review have not established a clear policy on how first responders place priority on patients based on time-sensitive conditions such as severe symptoms or age. Actors such as the MRC, National Guard, PHCC, local county health departments, American Red Cross, and other private sector actors are all part of the response process and have roles within PODs. However, these actors may follow different procedures or different training that is not standardized even though they all operate under the same incident command.

Prophylaxis dispensing from PODs also has ambiguities. There are three main distribution methods: drive-up, walk-in, and door-to-door. These three are all available but can conflict. Although door-to-door prophylaxis can aid individuals who cannot be physically present at a POD, there is no explicit mechanism to prevent double counting. Some who receive door-to-door prophylaxis could also go to a POD and obtain additional supplies. Although it is reasonable for individuals and families to need additional prophylaxis over time, the response cannot afford to have an unchecked system where people, even with the most honorable intentions, take initial supplies that were supposed to be provided to other individuals in need of the first dosages of prophylaxis. On the other hand, solely using door-to-door would also be an arduous process when other methods can be used for dispensing.

5 Discussion and Recommendations

In this chapter, we discuss the feasible and desirable changes to improving the detection, investigation, and decision-making. These changes are explained through our conceptual model that is described in Sections 5.1 through 5.10. Section 5.11 summarizes our limitations throughout our research, and Section 5.12 includes discussions of future directions and some comparisons of our work to other scholars' research.

5.1 Overview of the Conceptual Model

Taking into consideration the discrepancies we summarized in Chapter 4, we constructed an idealized, conceptual model of the best possible system that could be used to respond to an attack. Chapters 5.2 through 5.10 will detail this model, which represents our recommendations for feasible and desirable changes.

5.2 Detect Possible Attack

Our first conceptual model represents the response following the release of anthrax and prior to the decision-making process. This model, shown below as Figure 5.2, reorganizes the current system and will be discussed from Chapter 5.2 through

Chapter 5.5.

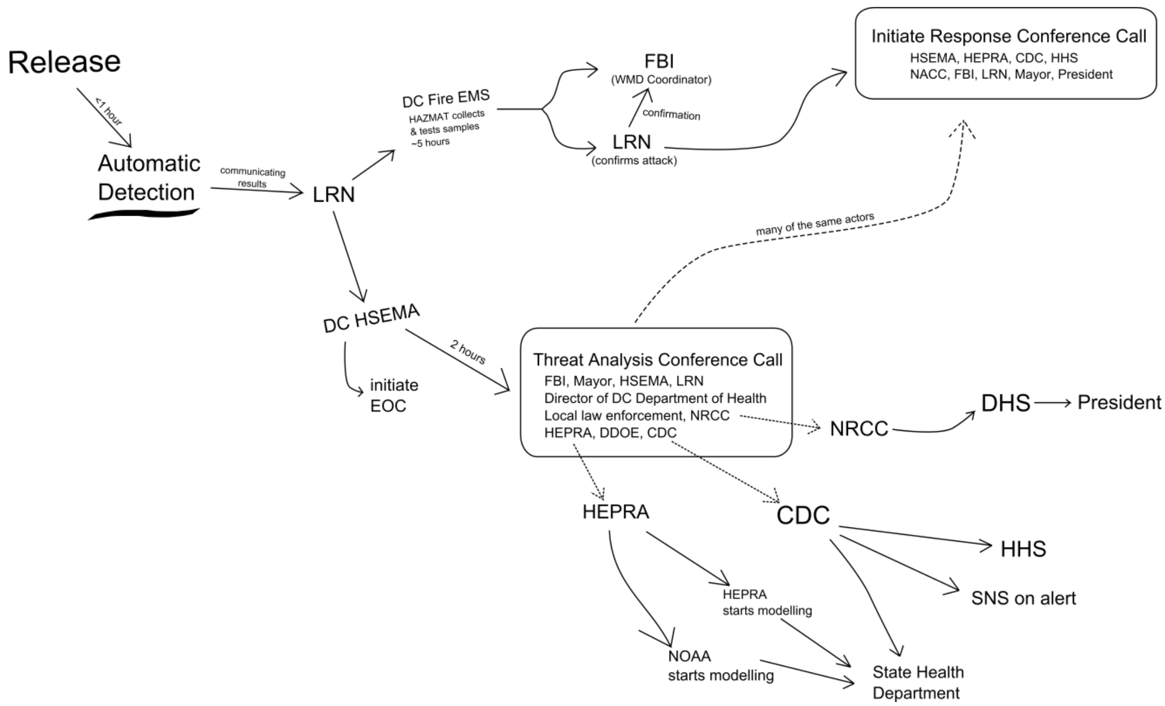


Figure 5.2 – Conceptual Model: Release

The ideal detection method utilizes an automatic pathogen detection system that is network linked to a laboratory for constant monitoring. Various options and prototype models for such systems do exist yet are not being utilized to the same standardized system that is BioWatch, as ineffective as it is. Actors currently funding BioWatch should redirect that funding to either research for new detection systems or installing an existing, experimentally proven detection system. Ideal automated pathogen detection will eliminate the need for syndromic surveillance and will have a sufficiently low rate of false positives, which will reduce any complacency and hesitance by those who need to respond quickly. Wet lab assays should be eliminated as initial processes of detection, concentration based detection should be continuous, and the system should be able to discern through ubiquitous morphologies of pathogens and define the pathogen with an extremely low capacity for error in detection. BioWatch should be replaced with an automated pathogen detection system that can detect an anthrax spore immediately through automated airborne sampling and classify it via a computerized system (Wyatt 2002).

Preliminary technology and methods have been developed to detect and monitor threat pathogens with minimal false positives that include UV based systems and electromagnetic scattering systems that de-emphasize the biochemical assay (Wyatt 2002). While such systems have been tested and evaluated by the developers, they need to be evaluated and validated by officials in designated outdoor locations of where BioWatch filters may have been. While over $100 million has been spent on BioWatch (Barnes 2013), such funds could be reallocated in developing and utilizing less costly maintenance systems that were aforementioned. It is estimated that approximately $3 billion will be used in the development of the Generation 3 BioWatch, which would involve a more effective detection and less human personnel to operate it (Barnes 2013). It is unclear of its reliance on faulty laboratory assays, but an automated system is preferred to initiate the response cascade as early as possible.

The automated system must be designed to send data and analysis directly to the LRN. The LRN would receive information on the pathogen itself, number of detectors with a positive hit, and time each hit was confirmed by the system. Upon receiving this information, the LRN would alert the appropriate officials and agencies. Further communication recommendations will be addressed in the following sections.

5.3 Investigate and Confirm Attack

The detection system should be automatic and with minimal inaccuracies so each positive case should be taken seriously. Once LRN obtains confirmation on the pathogen presence, they would contact the HSEMA, who would establish the Threat Analysis Conference Call with LRN, FBI, CDC, HEPRA, DDoE, the director of DC DOH, DC law enforcement, the DC mayor, NRCC, and other NCR localities. This joint call allows quick initial decision-making in an inter-agency manner especially with the CDC and FBI regarding investigation while establishing NIMS incident command. Suggestions regarding further inter-agency communication will be discussed in 5.6. Additionally, LRN would contact DC Fire EMS to order HAZMAT to collect a sample from the detection site in order to run confirmatory testing.

5.4 Contain Pathogen

HEPRA should receive first-hand information regarding the parameters of the aerosol release from a follow-up call from the FBI after their investigation or during the initial Threat Analysis Conference Call if such information is readily available, and they, along with NOAA, should begin making plume models. Epidemiologists of varying jurisdiction should share their results to check the likelihood of each of their plumes.

5.5 Decide How to Respond

After initial detection of an anthrax attack, the LRN should communicate the initial detection and related information to DC HSEMA and DC Fire EMS. Via DC Fire EMS, HAZMAT would arrive at the scene of initial detection to collect samples of the pathogen to be analyzed by the LRN for confirmatory testing. Meanwhile, DC HSEMA would establish the fully operational EOC while also initiating the Threat Analysis

Conference Call outlined in Chapter 5.3. The local FBI WMD coordinator would be notified of these events as well and participate with HSEMA in the conference call.

After this first conference call, which would be an information-sharing forum as well as the formal confirmation of roles and responsibilities for a response, some actors would have to immediately notify other actors. The CDC, instead of waiting for the completed SNS request process from a local jurisdiction, would put SNS on alert to begin mobilization of supplies and delivery mechanisms. Additionally, the CDC would forward this information to the HHS and the relevant state health department(s). The state health department(s) would communicate with NOAA to understand the most recent scope of the attack. The NRCC would communicate the conference call information to the DHS, which would then notify the President of the United States.

When the LRN completes the confirmatory testing, it would notify the FBI WMD coordinator and the Initiate Response Conference Call would ensue. This second conference call would include the LRN, FBI, HSEMA, HEPRA, the DC mayor, CDC, HHS, NRCC, the President of the United States, and other relevant NCR localities. During this call, these overarching leaders of the response would use the information pertaining to confirmation, scope, and current casualties to determine how to respond. Discussion would include topics such as opening PODs, alerting the public, and requesting assistance from the National Guard.

5.6 Communication Among Actors

The second conceptual model we constructed details a reorganized system from the decision-making process through the dispensing of prophylaxis antibiotics. The model is shown below as Figure 5.6 and will be discussed through Chapter 5.10.

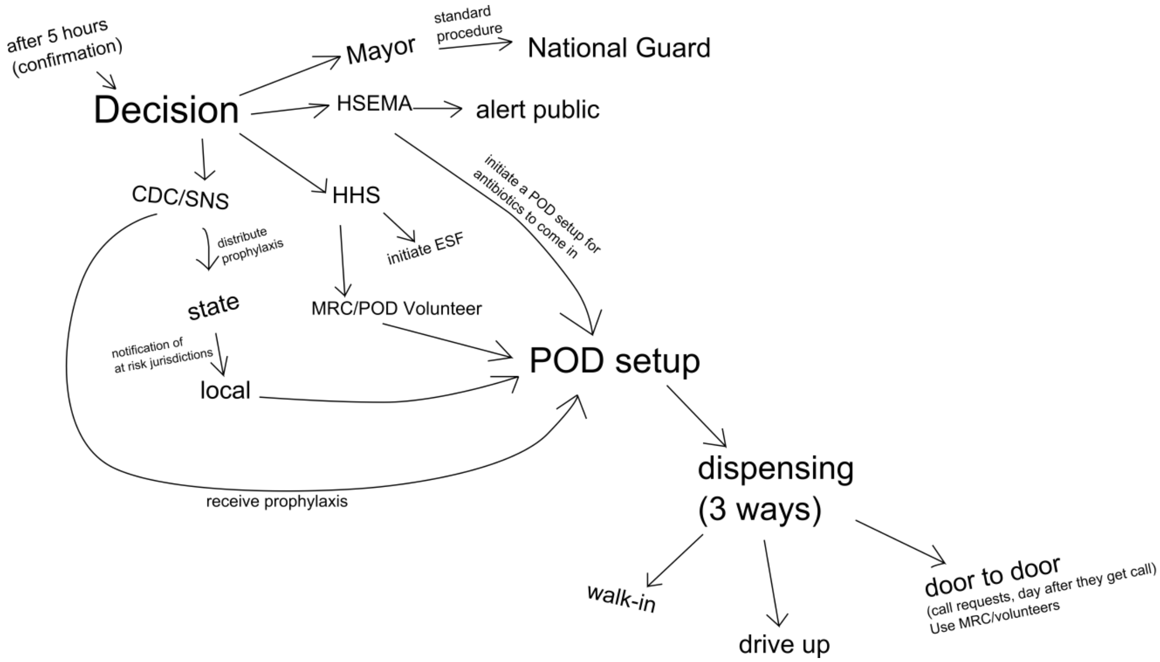


Figure 5.6 – Conceptual Model: Decision

While all steps of the detection, decision-making, and response are occurring, there needs to be standardization of virtual information sharing across all involved actors. In Chapter 2, such information sharing networks were delineated including GEOCOP, TACTrend, and so forth. None of these systems are universally utilized by all involved actors, which further emphasizes the necessity of a standard operating picture implementing all such systems. Virtual USA (vUSA) is an example of such a project that allows cross-platform information sharing among federal, state, and local actors. This is one solution to create transparency and willingness to share first-hand updates and information that can be crucial to the overall response, whether it be confirmation of lab testing or a specific POD site issue. As mentioned before, the open-source software does exist, but not all involved response and public health actors endorse it at this time.

5.7 Mobilize Responders

The top priority for addressing these issues would be to enforce some form of standardization in mobilizing responders. There will be numerous jurisdictions and actors working on their own for their part of the response process, but having a uniform program and process throughout all of them would standardize the response. It will also be necessary to ensure that there will be sufficient responders and volunteers in the event of an emergency. It is important that these responders are made aware of the importance of their part during the response process; although they may certainly have their own goals such as protecting their families, it must be stressed how vital they are to ensuring the protection of many others.

This ties into needing periodic review of the response process. By having a quarterly review, for example, where the information is gone over again, there would be opportune times to remind first responders of how important their response is for the overall process.

5.8 Deliver Supplies to PODs

The overall prophylaxis delivery to PODs must be streamlined. By implementing a standard process between actors and hospitals, the actors and hospitals would be required to follow similar protocols that would aid in getting these supplies delivered. There needs to be accountability for delivering prophylaxis in a timely manner. A delivery tracking system via information technology could be a feasible improvement. Within the private sector, there are systems that can provide these updates. Network-centric operations (NCO) can provide a GPS tracking of relevant vehicles charged with delivering prophylaxis so that there is no redundancy or confusion (IBM 2004). This type of technology, or systems with similar intent, can keep actors updated instantaneously. Additionally, integrating hospitals into the NIMS process will make them standardized.

The SNS request process can be integrated into the conference calls designed for decision-making. After the Threat Analysis Conference Call, the CDC could put the SNS on alert. Officials and first responders would begin organizing prophylaxis supplies and loading trucks or other necessary vehicles to deliver to specific jurisdictions. After the Initiate Response Conference Call, HSEMA, CDC, and HHS would carry out separate actions to aid the establishment of operational PODs. HSEMA (or equivalent actor in another jurisdiction) would formally initiate POD setup. The CDC would notify state health departments of this decision, outside the NCR, and the state health departments would use this information as well as the latest plume models to notify local jurisdictions of "at-risk" locations. The SNS would begin its delivery phase to PODs. Furthermore, the HHS would initiate necessary ESFs and instruct the MRC and other POD volunteers under their command to mobilize.

5.9 Inform Public

The President of the United States could provide more than one set of updates through a series of press conferences. It is acceptable for the president to say that some circumstances remain unknown as long as that is the honest answer. In that case, the president could provide a series of updates on a periodic basis as information vital to the public is shared.

Informing the public in a responsible manner requires efficient information technology as well as understanding of how the technology works across actors. A number of private sector technologies may serve as feasible systems to share information with other actors and the public. Our IT systems contact informed us of how GEOCOP includes a series of social networks and looks at geographic coordinates to provide agencies and the public (depending on whether information is input as "secured" or "unsecured") with refreshed updates in a matter of seconds of an event. The contact also informed us that one aspect of GEOCOP is TACTrend, which allows actors to collaborate and share information online and then search through billions of tweets per week through a search of geocoded trends.

5.10 Open PODs

One of the first important reforms to the process of opening PODs would be to establish a formal policy that requires actors to report their status as closed PODs (if applicable) so that decision-makers can have the most information possible when devising a timely response. Additionally, a clear policy should establish the process for closed PODs that choose to become open to the public to be recognized as such. These private sector actors that have the capability and willingness to open their time and space to serving local communities during a bioterrorist attack should be properly evaluated by relevant government actors in accordance with established guidelines.

PODs currently have three forms of dispensing. All PODs capable of both drive-up and walk-in dispensing would implement both methods. In addition, door-to-door dispensing would be available solely to individuals who cannot access the PODs directly to guarantee fairness in distribution. The issues at hand are determining which people need door-to-door prophylaxis and avoiding double-counting among the public. We propose a national hotline established and operated by volunteers from the state MRC's, who were designated to this task by the federal MRC. The hotline would allow civilians to call one consistent phone number across jurisdictions to avoid confusion between postal routes and town borders. MRC volunteers would receive requests from civilians and obtain their name, address, and necessary contact information. This data, sorted by the contacts' addresses, would be forwarded by MRC volunteers to the local public health departments and the U.S. Postal Service, which would deliver prophylaxis to the appropriate people the following morning. The Postal Service would continue on a route that mirrors traditional mail routes if there is a high frequency of calls for door-to-door prophylaxis. However, if call frequency is low, then the Postal Service would deliver prophylaxis in shortened routes that, to their discretion, will dispense more quickly and also allow dispensing of prophylaxis on the same day as when the call is received since there is not as much call volume.

5.11 Limitations

The limitations to this project included those of the methodology, the scope, and dealing government agencies.

SSM takes a learn-as-you-go approach toward research. Certain aspects of our research and recommendations could not be determined until we understood the problem, as the SSM approach is dependent on the information and issues revealed in time during the research. For example, certain aspects of a response might only be known by certain actors, and this information, in turn, would ultimately alter a potential recommendation. However, we might not have spoken to the relevant actor until after other aspects of the research were investigated. This process limited the amount of time available to conduct these interviews and highlights the importance of time management while using SSM. Fortunately, the Gemstone program devotes three years toward each project, giving us ample time and opportunity for the various facets of our research.

Our models of interaction relied largely on approximated and ranged timing, and therefore, may be slightly inaccurate with regards to timing. It is also possible that our models of interaction did not include all the factors of an attack. The different factors affecting an aerosolized anthrax attack might include weather patterns and human movement.

The use of 2010 census data in our computer simulations also factored in as a limitation. A primary target for a terrorist attack would be in a highly populated area, and our research only considered an outdoor, above ground attack. However, census data accounts for residential population, and hence nighttime population, as opposed to the population data that might occur in daytime while the city is more highly populated. However, our simulations still simulated over the span of several days and gave a general timeline of the spread of the anthrax plume.

To analyze the precision of our simulation, we considered several different release times. The results of these simulations, shown in Figures 4.4e and 4.4f, give an approximate variance of the number of people infected for a specific amount of anthrax released. Although the anthrax incidence model is stochastic, we found that it reveals closely similar results for the total number of people infected for the same initial conditions.

Determining the accuracy of the simulation is more difficult. We compared our results with simulations developed by Wilkening, and found that the results agreed within the variance of the simulations. This served as a sanity check to confirm that our simulation is functioning appropriately. However, both our simulation and Wilkening's are based on data from the Sverdlovsk. Since there have been very few cases of aerosolized anthrax releases, and laboratory testing of anthrax incubation is infeasible, the results of both simulations cannot be confirmed.

There are some difficulties involved in focusing on such a large issue as the response to an aerosolized anthrax attack. It would be unreasonable to interview every single person, or even every actor, involved in the response, or consider every scenario.

Another setback not anticipated was the change in positions of a few of our contacts. Although this brought up the issue with changing positions during an anthrax attack, it did make following up with our current contacts in their positions difficult, since we needed to re-establish such connections.

In dealing with government documents and agencies, there always existed the problem of clearance and classified documents that we could not access. Although this was necessary for national security, it was potentially a major block in gaining a fuller understanding of how the current system works. For example, we collected little information about the BioWatch program because details such as the location and number of sensors are not made public.

5.12 Future Directions

BIOCOUNTER recommends a number of different avenues for continued research in the fields of public health, national security, and emergency management. The process of using SSM to identify gaps and discrepancies and then recommend feasible and desirable changes should be applied to other metropolitan areas of the United States. Future studies should also examine the environmental perspective and identify feasible and desirable changes to current protocols in order to protect air, water, food, and other resources in the country. A number of changes could be made to this thesis as well.

With more time, we could have conducted additional research on the current policies and mechanisms of response. Ideally, we would have compared the response protocols of metropolitan Washington, D.C., with those of another city. Additional interviewees from more local-level actors and the private sector would contribute to an enhanced Communication Network. Furthermore, the Models of Interaction would have more specific times and, therefore, a more precise set of critical paths. Simulations with release points outside of Washington, D.C., would contribute to an analysis of how actors respond when an anthrax release occurred outside of the city and eventually entered it. This analysis could show distinctions between Washington, D.C., acting as the first affected location and as a location that perhaps was already notified and preparing a response. All of these adjustments to our research could provide further contributions to enhancing the investigation and decision-making in response to an aerosolized anthrax attack.

BIOCOUNTER's research has found a number of gaps and discrepancies in the response protocols for a bioterrorism attack that do agree with other experts' findings. In agreement with scholars such as Stoto and Morse (2008), we found syndromic surveillance systems to be largely ineffective in the detection effort with significant delays. However, BIOCOUNTER has outlined feasible and desirable changes that we believe can help standardize the detection, investigation, decision-making, and response across actors. Kong et al. (2008) indicated via a symptoms-based algorithm that improving detection alone could save lives. Although the algorithm required displayable symptoms as opposed to ours, which noted immediately when individuals became sick, both of our studies agreed that improving timeliness of initiating a response would reduce casualties.

Although we shared these research outcomes with other scholars, we could still expand our efforts beyond the ones recommended at the beginning of this section. Hawkins et al. (2008) focused on how anthrax could spread through HVAC systems within buildings. The research found that certain filtration systems could reduce this spread despite the manipulation of the HVAC system for bioterrorism. BIOCOUNTER could also run a comparative study by having simulations of anthrax releases from within buildings and tracking the number of people sick over time. We could apply the same Communication Network and understanding of response protocols to revise our models of interaction and then develop a new conceptual model on how to improve investigation and decision-making in response to an internal release of anthrax.

Appendices
A. Graph Theory

A.1 MATLAB

In order to properly analyze the 401x401 adjacency matrix, we needed to implement MATLAB code that could determine specified subpaths as well as identify the most frequent subpaths of certain lengths. The following code established the matrix within MATLAB and allowed us to select starting and ending entities. MATLAB would name the entities along the desired path.

```
Adjacency = dlmread('Matrix without names 7-9-12.csv');
orgNames = textread('Matrix name array v2 7-9-12.csv', '%s', 'delimiter', '\n');

if length(Adjacency) ~= length(orgNames)
error('Adjacency and orgNames dont agree')
end

%Finds the index of the desired start and end node
startID = strmatch('JAHOC', orgNames, 'exact');
endID = strmatch('CDC', orgNames, 'exact');

C = ones(length(Adjacency)); %Cost matrix
isWaitBar = 1;

N = length(Adjacency);

Adjacency = Adjacency + eye(N); % Adjacency(i,i) = 1, to make organizations self-
connected
%(therefore an individual org is a path for the subpath part later)

[costs,Paths] = dijkstra_kirk(Adjacency,C,startID,endID,isWaitBar);
disp(orgNames(Paths))
```

The "Matrix without names 7-9-12.CSV" file is our adjacency matrix, which contains all of the information about which entity communicates with whom. However, this file only contains numbers. In order to associate the correct titles to each entity, we created a second file, "Matrix name array v2 7-9-12.CSV," which MATLAB used to assign entity titles with their information within the adjacency matrix. In this sample code, MATLAB would display the entities involved in a communication path from the JAHOC to the CDC, as indicated by their appearance within the “startID” and “endID,” respectively.

Next, we needed to develop a subpath matrix that stored all of the subpaths from any entity to any other entity within the adjacency matrix. The following code established this matrix.

```
%Subpaths(i,j): Number of times Paths(i,j) is a subpath of any path
%(including itself.

%If Subpaths(i,j) = 0 by the end of this nested for loop, then org(i) is not conected to
org(j)

%Note: Subpaths(i,i) will always be at least 1, because every organization
%is at least connected to itself

close all force;

Subpaths = zeros(N);
outerWaitbarHandle = waitbar(0, 'Subpath calculation total');
innerWaitbarHandle = waitbar(0, 'Inner loops');


tic
for ii = 1:N
   ii
   for jj = 1:N
      subpath = Paths{ii,jj};
      waitbar(jj/N, innerWaitbarHandle)
      if isnan(subpath)
         continue;
      end

      %Sees if Paths(ii,jj) is a subpath of every path
      for a = 1:N
         for b = 1:N
            path = Paths{a,b};

            if isnan(path) %org(a) not connected to org(b)
```

```
            continue;
        end

        %Is Subpaths(ii,jj) a subpath of Paths(a,b)?
        isSubpath = strfind(path, subpath); %index where subpath occurs in path. [] if subpath is not contained in path
        if length(isSubpath) > 0
            Subpaths(ii,jj) = Subpaths(ii,jj) + 1;
        end

      end
    end

  end
  toc
  %Display and update waitbar
  fractionDone = (ii)/N;
  waitbar(fractionDone, outerWaitbarHandle)
end

dlmwrite('Subpaths_v1.csv', Subpaths)
```

This code causes MATLAB to save the subpath matrix under the name "Subpaths_v1.CSV" and is available for analysis if this code is used with the additional analysis. The code is $O(N^4)$, which means that the amount of time that this code takes to run is proportional to the number of entities in the adjacency matrix to the fourth power.

Lastly, we needed MATLAB to analyze this subpath matrix and produce the five most common subpaths for each possible subpath length.

```
Subpaths = dlmread('Subpaths_v1.csv');

sortedPaths = {}; %at index (count,:). {path length}, {# of times its a subpath}, {path}
count = 0;
h = waitbar(0, 'Restructuring data');

for i = 1:N
  for j = 1:N
    count = count+1;
    path = Paths{i,j};
    pathLength = length(path);
```

```
    if isnan(path)
      sortedPaths(count,1) = {0}; %Saying path = NaN has 'length' 0
      sortedPaths(count,2) = {0}; %Saying path is never a subpath
      sortedPaths(count,3) = {[i j]}; %Here, path = NaN. Org i is not connected to org j
    else
      sortedPaths(count,1) = {pathLength};
      sortedPaths(count,2) = {Subpaths(i,j)};
      sortedPaths(count,3) = {path};
    end
  end
  waitbar(i/N, h)
end
close(h)

% Sort the sortedPaths array
%http://www.mathworks.com/matlabcentral/fileexchange/13770-sorting-a-cell-array
sortedPaths = sortcell(sortedPaths, [1 2]); %sort first by col 1 (path length), then by col 2
(subpath appearance)

% Print out top M for each length l
M = 5;
L0 = sortedPaths{length(sortedPaths), 1} + 1;
L = L0;
j = 0; %for each l, look at top values from 1:j:M

%Goes in reverse order to make sure we're looking at the most commonly
%occuring
for i = length(sortedPaths):-1:1
  length = sortedPaths{i,1};
  if length < L %next smallest length
    if L ~= L0
      fprintf('\nNumber of subpaths of length %1.0f: %1.0f', L,j) %for previously
examined L
    end

    L = length;
    j = 0;
    fprintf('\n---------------\nLength: %1.0f\n', L)
    if length == 0
      fprintf('\nThese orginizations are not connected to each other:\n')
    end
  end

  subpathCount = sortedPaths{i,2};
  path = sortedPaths{i,3};
```

```
    if j < M
        fprintf('subpathCount = %1.0f\n', subpathCount)
        disp(orgNames(path))
    end

    j = j+1;
end
fprintf('\nNumber of subpaths of length %1.0f: %1.0f', L,j)
```

This final code prints all of the most frequent subpaths of each length in terms of the number of nodes (entities). For instance, the output's longest subpath length is eleven, which means that eleven entities are listed in order from start to end.

A.2 Communication Network with Names

The image below represents the same Communication Network discussed in Chapter 4, but it includes the name of each actor and plan in the graph.

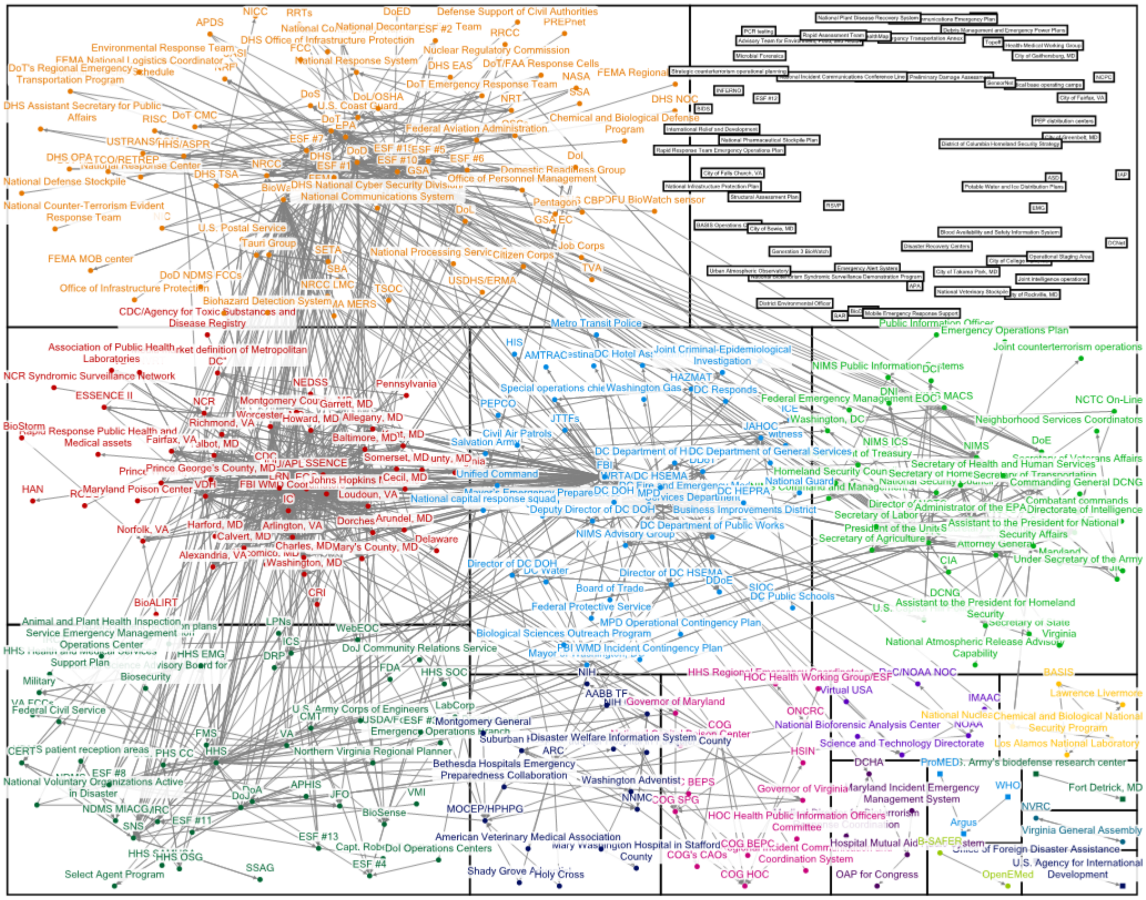


Figure A.2 – Communication Network with Names

B. Models of Interaction

The models of interaction delineate the steps through each path, categorized and initiated by the method of detection. The duration of each task is stated, followed by start and finish times. The task that precedes the target task is labeled by their ordered number. Shown below are the entry spreadsheets of our models of interaction. For the purposes of our research, we used the visualized network diagram format of the below tables which are extensive and cannot be fit into this thesis. They are originally .mpp files that can be translated from entry spreadsheets to network diagrams. To better understand what is meant by a network diagram, a visual screenshot of parts of Model 1 as a network diagram is included towards the end of this Appendix section.

Table B.1: Model 1: Direct Observation Path

	Task Name	Duration	Start	Finish	Predecessor
2	Release	0 hrs	Wed 12/5/12	Wed 12/5/12	
3	Direct Observation	0 hrs	Wed 12/5/12	Wed 12/5/12	2
4	911 is alerted	0 hrs	Wed 12/5/12	Wed 12/5/12	3
5	Fire Department/Paramedics arrive	0.18 hrs	Wed 12/5/12	Wed 12/5/12	4
6	Metropolitan Police arrive	0.18 hrs	Wed 12/5/12	Wed 12/5/12	4
7	DCDOH alerted	0.58 hrs	Wed 12/5/12	Wed 12/5/12	5
8	HSEMA alerted	0 hrs	Wed 12/5/12	Wed 12/5/12	7
9	FBI WMD Coordinator alerted	0.35 hrs	Wed 12/5/12	Wed 12/5/12	7
10	HSEMA offficials arrive	0.38 hrs	Wed 12/5/12	Wed 12/5/12	8
11	FBI agents arrive	0.15 hrs	Wed 12/5/12	Wed 12/5/12	9
12	Source investigation	1 hr	Wed 12/5/12	Wed 12/5/12	11
13	HEPRA alerted	0.75 hrs	Wed 12/5/12	Wed 12/5/12	4
14	President notified	1 hr	Wed 12/5/12	Wed 12/5/12	4
15	local conference call	1 hr	Wed 12/5/12	Wed 12/5/12	9
16	WRTAC notified	0 hrs	Wed 12/5/12	Wed 12/5/12	8
17	HEPRA begins to organize for BIOWATCH Advisory Committee	0.9 hrs	Wed 12/5/12	Wed 12/5/12	13
18	WebFusion	0 hrs	Wed 12/5/12	Wed 12/5/12	17

19	HSIN	0 hrs	Wed 12/5/12	Wed 12/5/12	17
20	Regional Incident Command and Coordination System activated	0 hrs	Wed 12/5/12	Wed 12/5/12	17
21	Secondary testing confirmation	6 hrs	Wed 12/5/12	Thu 12/6/12	39
22	Federal Conference call	1 hr	Wed 12/5/12	Wed 12/5/12	15
23	Modeling Visualization team formed	0.3 hrs	Wed 12/5/12	Wed 12/5/12	15
24	Decision of Response	0.4 hrs	Wed 12/5/12	Wed 12/5/12	22
25	Recommendation to Mayor for SNS	0.25 hrs	Wed 12/5/12	Wed 12/5/12	24
26	Request to HHS for SNS	0.2 hrs	Wed 12/5/12	Wed 12/5/12	25
27	CDC evaluation	0.65 hrs	Wed 12/5/12	Wed 12/5/12	26
28	Deploy SNS	1 hr	Wed 12/5/12	Wed 12/5/12	27
29	SNS distributed from warehouses to PODs	9.5 hrs	Wed 12/5/12	Thu 12/6/12	28
30	POD set up	15.5 hrs	Thu 12/6/12	Mon 12/10/12	27,43
31	HSEMA notifications to public	0.5 hrs	Wed 12/5/12	Wed 12/5/12	8,13
32	HSEMA alert regional partners	0.5 hrs	Wed 12/5/12	Wed 12/5/12	8,13
33	HSEMA requests staff from nearby jurisdictions	0.5 hrs	Wed 12/5/12	Wed 12/5/12	8,13
34	HAZMAT contacted	0.57 hrs	Wed 12/5/12	Wed 12/5/12	5
35	HAZMAT arrives	0.5 hrs	Wed 12/5/12	Wed 12/5/12	34
36	Joint Terrorism Task Force/National Capital Response Squad contacted	0.2 hrs	Wed 12/5/12	Wed 12/5/12	35
37	JTTF/NCRS collects samples	0.5 hrs	Wed 12/5/12	Wed 12/5/12	36
38	Preliminary tests of samples	4.3 hrs	Wed 12/5/12	Wed 12/5/12	37
39	First confirmation of anthrax	0 hrs	Wed 12/5/12	Wed 12/5/12	38
40	HEPRA takes actions	0 hrs	Wed 12/5/12	Wed 12/5/12	39
41	Contact private sector	1 hr	Thu 12/6/12	Thu 12/6/12	21,24
42	Contact FEMA NRCC	0 hrs	Thu 12/6/12	Thu 12/6/12	21,24
43	Activate EOC	0 hrs	Thu 12/6/12	Thu 12/6/12	21,24,51
44	Activate Mobile Command Center	1 hr	Thu 12/6/12	Thu 12/6/12	21,24
45	Recommend potential decisions to Mayor	3.1 hrs	Thu 12/6/12	Thu 12/6/12	21,24
46	Contact National Watch Center	0.4 hrs	Thu 12/6/12	Thu 12/6/12	42
47	Contact RRCC	0.4 hrs	Thu 12/6/12	Thu 12/6/12	42
48	Contact Secretary of Homeland Security	0.4 hrs	Thu 12/6/12	Thu 12/6/12	42
49	Alert National Operations Center	0.25 hrs	Thu 12/6/12	Thu 12/6/12	48
50	Recommend activation of NIMS to DHS	0.25 hrs	Thu 12/6/12	Thu 12/6/12	49
51	NIMS and ESFs initiated	0.25 hrs	Thu 12/6/12	Thu 12/6/12	50

52	National Incidence Communications Conference Line	0 hrs	Thu 12/6/12	Thu 12/6/12	51
53	NRCC activated	0 hrs	Thu 12/6/12	Thu 12/6/12	51
54	RRCC activated	0 hrs	Thu 12/6/12	Thu 12/6/12	51
55	Rapid Response Public Health and Medical Assets activated	0.35 hrs	Thu 12/6/12	Thu 12/6/12	51
56	Incident response coordination team	0.35 hrs	Thu 12/6/12	Thu 12/6/12	51
57	Distribution of emergency guidance to all health officials	1 hr	Thu 12/6/12	Thu 12/6/12	56
58	Put US Public Health Service Commissioned Corps on Alert	0 hrs	Thu 12/6/12	Thu 12/6/12	51
59	Activate HHS National Disaster Medical System	0 hrs	Thu 12/6/12	Thu 12/6/12	51
60	Completion	0 hrs	Mon 12/10/12	Mon 12/10/12	10,12,16,18,19
					19,20,29,30,31
					32,33,41,44,45
					47,52,53,54,55
					57,58,59

Table B.2: Model 2a: BioWatch Path 1

	Task Name	Duration	Start	Finish	Predecessor
2	Release	0 hrs	Wed 12/5/12	Wed 12/5/12	
3	Dry Filter Unit lags in recognition of aerosolized anthrax	24 hrs	Wed 12/5/12	Fri 12/7/12	2
4	Positive reading of anthrax	3 hrs	Mon 12/10/12	Mon 12/10/12	3
5	Lab director notified and speaks to CDC	0 hrs	Mon 12/10/12	Mon 12/10/12	4
6	Regional Lab Director conference call	0.5 hrs	Mon 12/10/12	Mon 12/10/12	5
7	Biowatch Actionable Result	0.25 hrs	Mon 12/10/12	Mon 12/10/12	6
8	Secondary testing and confirmation	5 hrs	Mon 12/10/12	Tue 12/11/12	7
9	HSEMA alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
10	HEPRA alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
11	DCDOH alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
12	Mayor alerted	0.25 hrs	Mon 12/10/12	Mon 12/10/12	11
13	CDC alerted	0.25 hrs	Mon 12/10/12	Mon 12/10/12	11
14	President notified	1 hr	Mon 12/10/12	Mon 12/10/12	9

Table B.3: Model 2b: BioWatch Path 2

	Task Name	Duration	Start	Finish	Predecessor
2	Release	0 hrs	0.00 hrs	0.00 hrs	
3	Dry Filter Unit lags in recognition of aerosolized anthrax	24 hrs	Wed 12/5/12	Fri 12/7/12	2

4	Positive reading of anthrax	3 hrs	Mon 12/10/12	Mon 12/10/12	3
5	Lab director notified and speaks to CDC	0 hrs	Mon 12/10/12	Mon 12/10/12	4
6	Regional Lab Director conference call	0.5 hrs	Mon 12/10/12	Mon 12/10/12	5
7	BioWatch Actionable Result	0.25 hrs	Mon 12/10/12	Mon 12/10/12	5
8	Secondary testing and confirmation	5 hrs	27.25 hrs	32.25 hrs	7
9	HSEMA alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
10	HEPRA alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
11	DCDOH alerted	0.5 hrs	Mon 12/10/12	Mon 12/10/12	6
12	Mayor alerted	0.25 hrs	28.00 hrs	28.25 hrs	11
13	CDC alerted	0.25 hrs	28.00 hrs	28.25 hrs	11
14	President notified	1 hr	28.00 hrs	29.00 hrs	9
15	WRTAC alerted	0 hrs	28.00 hrs	28.00 hrs	9
16	HEPRA plume modeling begins	0 hrs	Mon 12/10/12	Mon 12/10/12	10
17	HEPRA begins to organize for BioWatch Advisory Committee	1 hr	Mon 12/10/12	Mon 12/10/12	10
18	CDC Director's EOC (DEOC) notified	0.5 hrs	Mon 12/10/12	Mon 12/10/12	10
19	FBI WMD Coordinator alerted	0.5 hrs	29.00 hrs	29.50 hrs	10,26
20	Epidemiologist checks with EOC every half hour	0.35 hrs	41.85 hrs	42.20 hrs	16,55
21	WebFusion	0 hrs	29.00 hrs	29.00 hrs	17
22	HSIN	0 hrs	29.00 hrs	29.00 hrs	17
23	Regional Incident Command and Coordination System activated	0 hrs	29.00 hrs	29.00 hrs	17
24	HHS Secretary's Operation Center (SOC) notified	0.3 hrs	28.50 hrs	28.80 hrs	18
25	Schedules made and publicized	0 hrs	28.50 hrs	28.50 hrs	18
26	FBI and NOH notified via NOC	0.2 hrs	Wed 12/5/12	Wed 12/5/12	24
27	HHS Emergency Management Group alerted	0.2 hrs	28.80 hrs	29.00 hrs	24
28	Assistant Secretary Preparedness and Response (HHS) notified	0.2 hrs	28.80 hrs	29.00 hrs	24
29	Incident Response coordination team alerted	0.2 hrs	28.80 hrs	29.00 hrs	24
30	Federal conference call	1 hr	32.25 hrs	33.25 hrs	8,37
31	Contact Private Sector	1.75 hrs	33.85 hrs	35.60 hrs	8,35
32	Contact FEMA NRCC	1.75 hrs	33.85 hrs	35.60 hrs	8,35
33	Activate Mobile Command Center	1.75 hrs	33.85 hrs	35.60 hrs	8,35
34	Recommend potential decisions (calling in National Guard) to mayor	1.75 hrs	33.85 hrs	35.60 hrs	8,35
35	Decision of Response	0.6 hrs	33.25 hrs	33.85 hrs	30,12,13,25
36	Recommendation to mayor for SNS	0.25 hrs	33.85 hrs	34.10 hrs	35
37	BioWatch Advisory Committee conference call	2 hrs	29.50 hrs	31.50 hrs	7,19
38	Modeling Visualization team formed	0.35 hrs	31.50 hrs	31.85 hrs	37
39	Request to HHS for SNS	0.2 hrs	34.10 hrs	34.30 hrs	36

Table B.4: Model 3: Syndromic Surveillance Path

	Task Name	Duration	Start	Finish	Predecessor
2	Release	0 hrs	0.00 hrs	0.00 hrs	
3	Incubation	60 hrs	0.00 hrs	60.00 hrs	2
4	Onset of symptoms	0 hrs	60.00 hrs	60.00 hrs	3
5	Increased medicinal sales	12 hrs	60.00 hrs	72.00 hrs	4
6	Increased physician visitations	12 hrs	60.00 hrs	72.00 hrs	4
7	Increased school absences	12 hrs	60.00 hrs	72.00 hrs	4
8	ESSENCE pattern reported	48 hrs	72.00 hrs	120.00 hrs	5,6,7
9	DCDOH alerted	0 hrs	120.00 hrs	120.00 hrs	8
10	CDC alerted	0 hrs	120.00 hrs	120.00 hrs	8
11	HEPRA alerted	0 hrs	120.00 hrs	120.00 hrs	9,10
12	FBI WMD Coordinator alerted	1 hr	120.00 hrs	121.00 hrs	11
13	Source investigation	0 hrs	121.00 hrs	121.00 hrs	12
14	local conference call	1 hr	121.00 hrs	122.00 hrs	12
15	Classification of incident	0 hrs	122.00 hrs	122.00 hrs	14
16	Federal Conference Call	1 hr	122.00 hrs	123.00 hrs	15
17	Decision of Response	0.4 hrs	123.00 hrs	123.40 hrs	16
18	Recommendation to Mayor for SNS	0.25 hrs	123.40 hrs	123.65 hrs	17
19	Request to HHS for SNS	0.2 hrs	123.65 hrs	123.85 hrs	18
20	CDC evaluation	0.65 hrs	123.85 hrs	124.50 hrs	19
21	Deploy SNS	0.45 hrs	124.50 hrs	124.95 hrs	20
22	SNS distributed from warehouses to PODs	1 hr	124.95 hrs	125.95 hrs	21
23	PODs set up	15.5 hrs	125.95 hrs	141.45 hrs	22,13

Table B.5: Model 4: Astute Physician Path

	Task Name	**Duration**	**Start**	**Finish**	**Predecessor**
2	Release	0 hrs	0.00 hrs	0.00 hrs	
3	Incubation	60 hrs	0.00 hrs	60.00 hrs	2
4	Onset of symptoms	0 hrs	60.00 hrs	60.00 hrs	3
5	Patient visits astute physician	48 hrs	60.00 hrs	108.00 hrs	4
6	Patients tested for anthrax	5 hrs	108.00 hrs	113.00 hrs	5
7	DCDOH alerted if positive tests	0 hrs	113.00 hrs	113.00 hrs	6
8	local conference call	1 hr	113.00 hrs	114.00 hrs	7
9	Classification of incident	0 hrs	114.00 hrs	114.00 hrs	8
10	Federal Conference call	1 hr	114.00 hrs	115.00 hrs	9
11	Decision of Response	0.4 hrs	115.00 hrs	115.40 hrs	10
12	Recommendation to Mayor for SNS	0.25 hrs	115.40 hrs	115.65 hrs	11
13	Request to HHS for SNS	0.2 hrs	115.65 hrs	115.85 hrs	12
14	CDC evaluation	0.65 hrs	115.85 hrs	116.50 hrs	13
15	Deploy SNS	1 hr	116.50 hrs	121.00 hrs	14
16	SNS distributed from warehouses to PODs	1 hr	121.00 hrs	122.00 hrs	15

17	PODs set up	13 hrs	122.00 hrs	135.00 hrs	16

Examples of Parts of a Network Diagram of Model 1

Dynamics of these network diagrams could be controlled to follow the critical path and each entity was labeled for its task and organization.

Figure B.1: Model 1 First Half

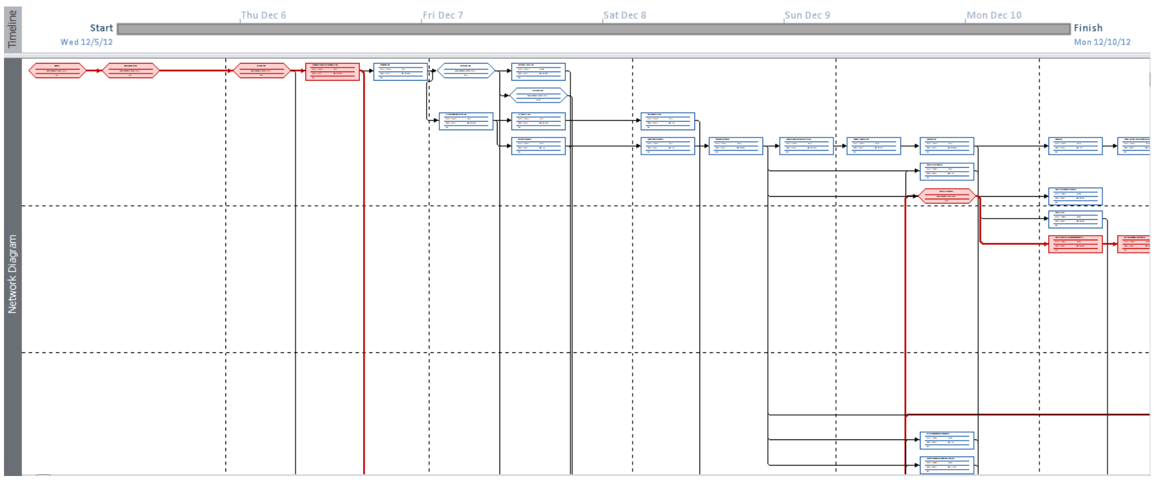
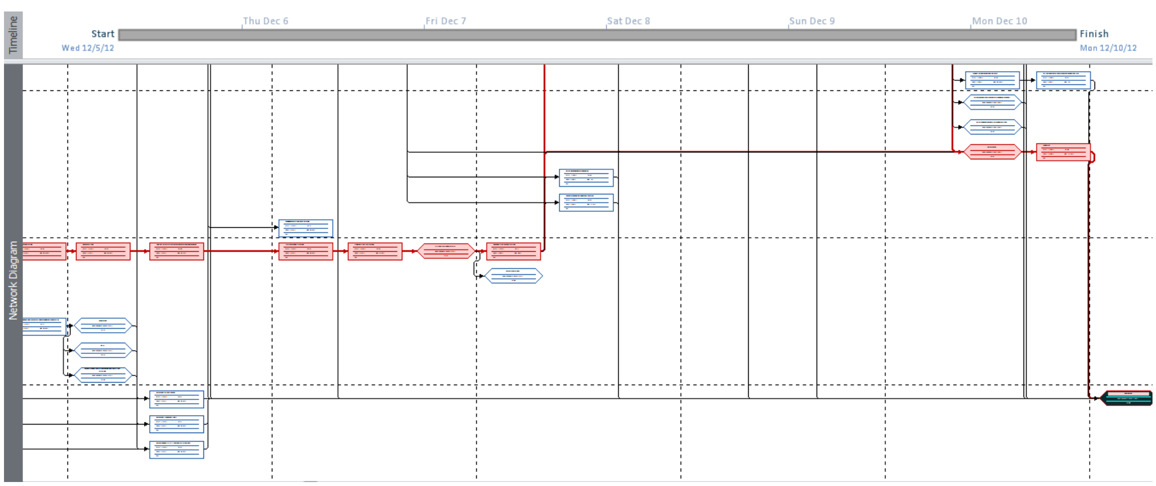


Figure B.2: Model 1 Second Half



C. Computer Simulations

C.1 List of programs used:

- Microsoft Visual C++
  - anthDispersion, written in C++, is the launcher for the Population Spread Model
- Hysplit version 4
  - Models the dispersion of the anthrax in the atmosphere. Creates a gridded data file of the anthrax concentration.
- Ruby
  - illMod, written in Ruby, calculates the number of people sick in each grid cell.
- ESRI ArcMap version 10.0
  - A Geographic Information System (GIS), used to visualize the results of the model.
- ArgGIS Data Management Toolbox
- Python version 10.6
  - putXYdataOnMap, written in Python, automates ArcMap.

C.2 Complete List of Variables and Parameters

C.2.1 Variables used in HYSPLIT's SETUP file

Note: Any variables not specified are set to HYSPLIT's default values

Variable name	Value	Description
delt	1 (minute)	Integration timestep
initd	0	Release type: 3D particle horizontal and vertical. Can be particle, puff, or hybrid (see HYSPLIT Users Guide)
numpar	10000	maximum number of particles released over duration of emission
maxpar	10000	maximum number of particles

Table C.2.1 – Variables used in HYSPLIT's SETUP file

C.2.2 Variables used in HYSPLIT's CONTROL file

Note: Any variables not specified are at HYSPLIT's default values

Variable name	**Value**	**Description**
Start Position	National Mall: 38°, 53', 22.24"	Position where the anthrax is initially released into the atmosphere
Simulation Duration	120 (hours)	Simulation Duration
Top of Model	10000.0 (meters)	Above this height the simulation does not run
Emission Rate	100 (units/hour)	Rate at which pollutant is released in arbitrary units
Hours of Emission	0.01 (hours)	Total time that anthrax is released. Note: releasing 100 units/hour for 0.01 hours corresponds to a nearly instantaneous release of 1 unit of anthrax.
Cell Size	30" x 30"	Each cell on the gridded map is 30 arcseconds by 30 arcseconds
Grid Size	30° x 30°	The size of the entire grid where the simulation is calculated is 30 degrees by 30 degrees
Anthrax diameter	1.5 (um)	
Anthrax density	1.42 (g/cm^3)	
Anthrax shape factor	1	Models the anthrax particles as spherical
Anthrax deposition velocity	0.002 (m/s)	Rate at which the anthrax particles deposit themselves on the ground

Table C.2.2 - Variables used in HYSPLIT's CONTROL file

C.2.3 Parameters varied

- Starting time
    - Jan 1, 9am (2010)
    - June 9, 9am (2010)
    - Jul 2, 2am (2010)
    - Sep 1, 9am (2010)
- Amount of anthrax released
    - 0.01 kg
    - 0.1 kg
    - 1 kg
    - 10 kg

Simulation #	Date and time of release	Amount of anthrax released (kg)
1	Jan 1, 9am (2010)	0.01
2	Jan 1, 9am (2010)	0.1
3	Jan 1, 9am (2010)	1
4	Jan 1, 9am (2010)	10
5	June 9, 9am (2010)	0.01
6	June 9, 9am (2010)	0.1
7	June 9, 9am (2010)	1
8	June 9, 9am (2010)	10
9	Jul 2, 2am (2010)	0.01
10	Jul 2, 2am (2010)	0.1
11	Jul 2, 2am (2010)	1
12	Jul 2, 2am (2010)	10
13	Sep 1, 9am (2010)	0.01
14	Sep 1, 9am (2010)	0.1
15	Sep 1, 9am (2010)	1
16	Sep 1, 9am (2010)	10

Table C.2.3 - List of simulations

C.2.4 Variables in the Anthrax Incidence Model

Variable	Value	Description
λ: Spore germination rate	5e-6 (1/day)	the risk per unit time that a spore germinates
θ: Spore clearance rate	0.084 (1/day)	the risk per unit time that a spore is cleared from the lung
Spore mass	0.7 (pg)	Mass of a single spore of anthrax
Breathing rate	1.8 (m^3/hour)	Volume of air inhaled per unit time

Table C.2.4 - Variables in the Anthrax Incidence Model

C.3 Anthrax Incidence Model Source Code

```
#FORMAT: ruby illmod<version number>.rb <HYSPLIT DATA> <POP DATA> <CSV
LAT/LON OUTPUT> <CSV HOUR OUTPUT> <start hour>
#EX: ruby illmodtest12.rb cdump.txt uspop00.txt csv1.csv csv2.csv 9

in_file = File.new(ARGV[0], "r") #input from HYSPLIT
us_pop = File.new(ARGV[1], "r") #US Population Gridded Data
csv_sickfile = File.new(ARGV[2], "w") #Output CSV of sick
csv_hourfile = File.new(ARGV[3], "w") #Output CSV by hour
start_hour = ARGV[4] #Starting hour, using an intenger for the 24 hours of the day

simtotal = 0 #total ill during simulation
looparr = [] #array tracker throughout the look
popcheck = 0 #simple boolean check if population has been run
hysplitcheck = 0 #simple boolean check if hysplit data has been run
pop_grid = {}
sporesInhaled = {}
sporesInTheBody = []
germ = 0.000005/24 #Germination rate of anthrax (1/hour (div by 24))
clear = 0.084/24 #Clearance rate of anthrax (1/hour (div by 24))
spore_mass = 0.7 #The mass of an individual spore (picograms)
breathing_rate = 1.8 #Breathing rate for inhalation of anthrax (.03 m^3/min = 1.8
m^3/hour)
sporesInhaled = {} #Hash/Hash/Array that tracks total number of spores inhaled at a
particular lat/lon for each hour. (spores)
sporesInTheBody = [] #Array that takes sporesInhaled for each lat/lon/hour and
calculates total number of spores in the body at that hour (spores)
cell_sick = {} #Hash that tracks the number of people sick per cell
tdiv = 0

csv_hourfile.print "Hour,"
1.upto(121) { |i|
	csv_hourfile.print "#{i},"
}
csv_hourfile.print "Total"
csv_hourfile.puts ""

1.upto(5){ |z|
puts "TEST #{z}"
csv_hourfile.print "TEST #{z},"

lines = in_file.readlines()
pop_lines = us_pop.readlines()
curr_lat = 50.00 # = yll + 1/120* number of rows
curr_lon = -125.00
```

```
pop_total = 0
val = 1.0/120.0 #0.00833333333333
total = 0 #tracker for total sick through the course of the simulation
if hysplitcheck == 0 then
        tc = 0 #total cells, to run a progress check in the third section
        tdiv = 0 #total cells divided by ten, to run to check

        #variables for the formula
        #Modeling the Incuation Period of Anthrax by Brookmeyer
        #Simulation Modeling of Antrhax Spore Dispersion in a Bioterrorism Incident
        germ = 0.000005/24 #Germination rate of anthrax (1/hour (div by 24))
        clear = 0.084/24 #Clearance rate of anthrax (1/hour (div by 24))
        spore_mass = 0.7 #The mass of an individual spore (picograms)
        breathing_rate = 1.8 #Breathing rate for inhalation of anthrax (.03 m^3/min = 1.8
m^3/hour)
        sporesInhaled = {} #Hash/Hash/Array that tracks total number of spores inhaled
at a particular lat/lon for each hour. (spores)
        sporesInTheBody = [] #Array that takes sporesInhaled for each lat/lon/hour and
calculates total number of spores in the body at that hour (spores)
        cell_sick = {} #Hash that tracks the number of people sick per cell

        #1.  Calculate spores inhaled from each line in cdump file
        puts "1. Calculating sporesInhaled from HYSPLIT"
        low_lat = 0.0
        low_lon = 0.0
        hi_lat = 0.0
        hi_lon = 0.0
        curr_day = nil
        last_day = nil
        lats_used = {}
        latlon_used = {}
        lines.each { |line|
          grid =
line.scan(/^(\d+)\s+(\d+)\s+(\d+)\s+(\d+)\s+(.......)\s+(........)\s+(......)\E(\+|-
)(\d+)\s+(......)\E(\+|-)(\d+)$/)
          grid.each{ |year, month, day, hour, lat, lon, antx0, x0_sign, ezero, antx1,
x1_sign, eone|
                if x1_sign == '-'
                  antx_1_val = antx1.to_f * 10**(-eone.to_f) #picograms / m^3
                else
                  antx_1_val = antx1.to_f * 10**(eone.to_f) #picograms / m^3
                end
                #Determines max/min lat/lon for getting grid cells
                if lat.to_f < low_lat then low_lat = lat.to_f end
                if lat.to_f > hi_lat then hi_lat = lat.to_f end
                if lon.to_f < low_lon then low_lon = lon.to_f end
```

```
            if lon.to_f > hi_lon then hi_lon = lon.to_f end

            if curr_day == nil then curr_day = 0 end
            if last_day == nil then last_day = day.to_i end
            if last_day < day.to_i then
              curr_day += day.to_i - last_day
              last_day = day.to_i
            end
            curr_hour = (curr_day) * 24 + hour.to_i - start_hour.to_i + 1
            if sporesInhaled[lat.to_f] == nil then
              sporesInhaled[lat.to_f] = {}
            end
            if sporesInhaled[lat.to_f][lon.to_f] == nil then
              sporesInhaled[lat.to_f][lon.to_f] = []
            end
            sporesInhaled[lat.to_f][lon.to_f][curr_hour] = antx_1_val  / spore_mass *
breathing_rate * 1
            lats_used[lat.to_f] = true
            if latlon_used[lat.to_f] == nil then latlon_used[lat.to_f] = {} end
            if latlon_used[lat.to_f][lon.to_f] == nil then latlon_used[lat.to_f][lon.to_f]
= true end
         }
       }
       hysplitcheck = 1
end

#2. Set up population count.
if popcheck == 0 then
       puts "2. Generating population data"
       i = 0
       n = 1
       tc = 0
       pop_lines.each { |line|
         grid = line.scan(/(\d+\.\d+|\d+)/)
         grid.each { |curr|
            if curr_lon >= low_lon and curr_lon <= hi_lon and curr_lat >= low_lat
and curr_lat <= hi_lat then
              if lats_used.include?(curr_lat.round(4)) then
                   if pop_grid[curr_lat.round(4)] == nil then
                     pop_grid[curr_lat.round(4)] = {}
                   end
                   if latlon_used[curr_lat.round(4)].include?(curr_lon.round(4)) then
                     pop_grid[curr_lat.round(4)][curr_lon.round(4)] = curr[0].to_f
                     pop_total += curr[0].to_f
                     tc += 1
                   end
```

```
                        end
                    end
                    i += 1
                    if (i / n) == 2208960 then
                            puts "#{n}0%"
                            n += 1
                    end
                    curr_lon += val
            }
            curr_lat -= val #Since we're starting at the top left
            curr_lon = -125.00
        }
        puts "-- Pop Total: #{pop_total}"
        tdiv = tc / 10
        popcheck = 1
end

#3. Calculate sporesInTheBody while also doing Formula Loop
puts "3. Formula Loop"
csv_sickfile.puts "LAT, LON, HOUR"
ti = 0 #total cell tracker, to run a similar check as the one in the second loop
tn = 1
cell_sick = []
sporesInTheBody = []
hours_sick = []
pop_grid.keys.sort.each{ |lat|
        if cell_sick[lat] == nil then cell_sick[lat] = {} end
        pop_grid[lat].keys.sort.each{ |lon|
                if cell_sick[lat][lon] == nil then cell_sick[lat][lon] = 0 end
                1.upto(120){ |i|
                        if sporesInhaled[lat][lon][i] == nil then sporesInhaled[lat][lon][i] =
0 end
                        if sporesInTheBody[i - 1] == nil then sporesInTheBody[i - 1] = 0
end
                        sporesInTheBody[i] = sporesInTheBody[i - 1] * (1 - clear) +
sporesInhaled[lat][lon][i]

                        if cell_sick[lat][lon] == nil then cell_sick[lat][lon] = 0 end
                        prob = 1 - Math.exp((-(sporesInTheBody[i]) * germ / (germ +
clear)) * (1 - Math::E**(-(clear + germ)*1)))
                        old_sick = cell_sick[lat][lon]
                        not_sick = pop_grid[lat][lon] - old_sick
                        new_sick = 0
                        1.upto(not_sick){ |j|
                                if rand() < prob.to_f
                                        csv_sickfile.puts "#{lat},#{lon},#{i}"
```

```
                    new_sick += 1
                    total += 1
                end
            }
            cell_sick[lat][lon] += new_sick
            if hours_sick[i] == nil then hours_sick[i] = 0 end
            hours_sick[i] += new_sick
        }
        #Attack rate
        sporesInhaled[lat][lon][121] = 0
        sporesInTheBody[121] = sporesInTheBody[120] * (1 - clear) +
sporesInhaled[lat][lon][121]
        prob = 1 - Math.exp((-(sporesInTheBody[121]) * germ / (germ + clear)))
        old_sick = cell_sick[lat][lon]
        not_sick = pop_grid[lat][lon] - old_sick
        new_sick = 0
        1.upto(not_sick){ |j|
            if rand() < prob.to_f
            csv_sickfile.puts "#{lat},#{lon},121"
            new_sick += 1
            total += 1
            end
        }
        cell_sick[lat][lon] += new_sick
        if hours_sick[121] == nil then hours_sick[121] = 0 end
        hours_sick[121] += new_sick
        ti += 1
        if (ti / tn) == tdiv then
            puts "#{tn}0%"
            tn += 1
        end
    }
}
csv_sickfile.puts "TEST #{z}, Total: #{total}, "
1.upto(121) { |i|
    csv_hourfile.print "#{hours_sick[i]},"
}
csv_hourfile.puts "#{total}"
simtotal += total
looparr[z] = total

puts ""
puts "FINISHED!"
puts "Total Sick: #{total}, Starting Hour: #{start_hour.to_i}"
puts ""
}
```

```
xavg = simtotal / 5
sampvar = 0
1.upto(5) { |z|
	sampvar += ((looparr[z] - xavg)**2) / (5 - 1)
}
csv_sickfile.puts ""
csv_sickfile.puts "Conf. Interval:  #{xavg} +/- #{1.533 * Math.sqrt(sampvar*5/5)}"
csv_hourfile.puts ""
csv_hourfile.puts "Conf. Interval:  #{xavg} +/- #{1.533 * Math.sqrt(sampvar*5/5)}"
puts "Confidence Interval: #{xavg} +/- #{1.533 * Math.sqrt(sampvar*5/5)}"

#Original format
#0 + 5, 1:51.4 - 24098
#0 + 48, 7:58.4 - 95661
#0 + 120, 14:31.1 - 95618
#Add scan for box limits
#0 + 5, 2:00.2 - 23735
#W/ Normal Dist
#0 + 5, 1:55.0 - 97 NEED TO DEBUG THIS NOMRAL DIST LATER ON
#0 + 120, 16:59.6 - 295 DEFINITELY NEED TO FIX
#Added Attack Rate, no Norm Dist
#0 + 5, 2:00.4 - 43205
#0 + 120, 14:47.4 - 114642
#Version 7, re-arrange to combine step 3 (sporesInhaled) and 5 (Attack Rate) and into 4.
#120 + attack rate, 6:12.9
#5: 73032 +/- 114.0263
#10: 73036 +/- 105.1951
#15: 73048 +/- 105.2236
#20: 73040 +/- 81.2958

#DATA TESTS
#cdump2.txt
#5 intervals
#1: 73037 +/- 48.1560
#2: 73023 +/- 64.1093
```

C.4 Computer Specifications

- Model: Dell Latitude E6400
- Operating System: Windows 7 32-bit
- Processor: Intel Core 2 Duo CPU P9600 @ 2.66 GHz
- Installed memory (RAM): 4.00 GB
- Average computation time per simulation: 31 minutes

Glossary

Actor: Entity or individual relevant to the response protocols

Adjacency Matrix: A means of representing nodes of data in a graph format to show the connections between them

Amerithrax: 2001 anthrax letter attacks

Anthrax Confirmation: Testing conducted by LRN laboratories that confirm a pathogen as anthrax

Anthrax Incidence Model: Refers to our in-house simulation designed to simulate the overall effects of a dosage of anthrax on a population. Alternatively, "Illness Model"

Anthrax Smoke Detector (ASD): Automated detection device that collects and analyzes samples

ArcGIS: A geographic information system (GIS) designed by Esri, used for working with map data and geographic information

Argus: Surveillance system developed by Georgetown University to collect online data and analyze the information for potential bioterrorism

Assay: An analytical laboratory test to measure certain chemical activities for a variety of analytes

Astute Physician: Also known as the "Observant Doctor" or "Observant Physician." A physician who acutely detects and diagnoses the disease

"At-Risk" Location: A high-target location that is a potential target of a terrorist attack

Automated: A means or mechanism that works automatically, most often technologically, and with limited human interaction

Autonomous: Functioning independently (i.e. without human interaction)

Autonomous Pathogen Detection System (APDS): Aerosol collector and analyzer developed via funding from the DoE, DHS, and DoD

Bacillus anthracis: Bacterium that induces the anthrax disease

Betweenness Centrality: Measure of a node's centrality in a network equal to the number of shortest paths from all vertices to all others that pass through that node

BIOCOUNTER: Bioterrorism Inhibition Operating COntainment Unit for the Negation of Terrorist Entities and Radicals

Bio-event Advanced Leading Indicator Recognition Technology (BioALIRT): Analyzes outpatient visit records using a variety of parameters to detect potential bioterrorism

Biological Aerosol Sentry and Information System (BASIS): Air collector and filter system that demands manual labor but has few false positives

Biological Weapons Convention of 1972: International agreement banning the development of biological weapons

Biosafety Level (BSL): Rating of a laboratory's capabilities to house and analyze particular pathogens; a one to four scale with four representing the most potent pathogens

BioSense: A national syndromic surveillance system that collects data from hospitals and both DoD and VA facilities

BioWatch: A national technological surveillance system that operates in select cities throughout the country.

BioWatch Actionable Result (BAR): An indication that a dangerous pathogen has been detected

CALPUFF: Gaussian puff atmospheric dispersion model

CATWOE: A mnemonic device of SSM standing for "Clients", "Actors", "Transformation", "Worldview Owner", "Environmental constraints"

Chain-of-Command: Line of hierarchy of leadership and responsibility of the response process

Chief Complaint: The primary symptom cited by a patient during a hospital visit

Ciprofloxacin: Prescription and prophylaxis antibiotic used to treat certain infections

Clearance Rate: Hazard rate or risk per unit of time that a spore is cleared from the lung

Common Operation Picture (cop): An interface containing live data that is shared across actors for the purpose of information sharing

Communication Network: Matrix containing all directed communication among actors that can be analyzed via graph theory

Competing Risks Model: A mathematical model comparing the attack probability and incubation period of a pathogen among a population

Conceptual Model: Idealized model displaying the feasible and desirable changes to the response protocols from detection to prophylaxis dispensing

Confidence Interval: A number that gauges to the reliability of an estimate in regards to a population test, e.g. our incidence model

ConOps: The Concept of Operations for a government health emergency, in this thesis specifically the HHS Aerosolized Anthrax Concept of Operations

Critical Analysis Period (CAP): The detection, investigation, and decision-making phases following an attack

Critical Path Method (CPM): A statistical analysis that determines the activities in a schedule with the longest duration, and thus deems the path with the longest duration as the "Critical Path." This path is then considered the most important independent path for completion of the schedule.

Cumulative Attack Probability Function of Disease, F (t): Probability of becoming infected by a certain time

C++: High-level and popular, object-oriented programming language

Dark Winter: A bioterrorism preparedness exercise performed in the summer of 2001, involving a fictional outbreak of smallpox, and overseen by the National Security Council

Decision-Making Phase: Actions within the response protocols in which actors determine how to best respond to a bioterrorism attack; usually includes conference calls and IT systems

Desiccation: Loss of moisture and into a state of dryness

Detection Phase: Initial actions of the response protocols where pathogens are initially detected, prompting confirmatory testing and investigation

Diameter of the Graph: The longest, non-cyclical path in the graph

Dijkstra's Shortest Path Algorithm: Algorithm designed to find the shortest non-negative path between two nodes on a graph

Directionality: Paths in graph have a defined direction to or from one node to another

Discrepancy: Inconsistencies of the response process found through extensive literature review and interviews

Disengagement: Phasing out of response and other various actions

Dispensing: Providing prophylaxis to people on scene or at their residences

Distribution: Refers to the method of distribution of prophylaxis during the response process

Door-to-Door Prophylaxis: Distribution method of prophylaxis during the response process that would require distribution at residencies

Doxycycline: Prescription and prophylaxis antibiotic used to treat certain infections

Drive-Up Prophylaxis: Distribution method of prophylaxis that would require individuals to come and retrieve an allocated amount of prophylaxis for them from a POD

Early-Warning System: Concept of having a detection system that provides a prompt determination of a biological threat

Edge: A line that connects two nodes on a graph

Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) II: A system of computer data and statistical analysis that collects information on patient symptoms and other qualitative and quantitative data in order to determine patterns in the symptoms affecting a population. It is the successor to ESSENCE, a program more specifically targeting military and smaller populations

Emergency Management: Policies and actions related to running successful investigation and decision-making phases in order to provide an efficient response to an event

Epidemiology: A branch of medical studies that focuses on the health conditions of populations, with a particular focus on disease and detection

ESRI: A developer of geographic information systems (GIS) software such as ArcGIS

Feasible and Desirable Change: A recommendation that is determined after examining the results of our research

Field Epidemiology: Field research and epidemic study of health and disease conditions in particular populations

First Responders: The agencies whose response is immediate during the response process

Fulminant Stage: Stage following the prodromal stage when a pathogen becomes lethal within the body

Gantt Chart: A scheduling chart that displays the tasks on a schedule in the form of a bar graph

Geo-spatial Common Operating Picture (GEOCOP): Social network of government officials and private sector actors who share information regarding national security and public health

Generation 3 BioWatch: The anticipated successor to Generation 2 BioWatch that would be able to detect anthrax and other biological threats automatically; however, the project has been delayed due to problems with its technology

Germination Rate: Rate at with the anthrax spores experience growth

Global Terrorism Database: An open-source database of terrorist activities from 1970 to 2011 compiled by the National Consortium for the Study of Terrorism and Responses to Terrorism

Graph Theory: The study of graphs, which are mathematical representations of the relations between objects

GUI: Graphical User Interface

HealthMap: Freely available website that compiles all official and unofficial updates regarding biological events

Homeland Security Presidential Directive (HSPD): Orders given by the president in order to further reinforce the defense of the USA

Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT): Atmospheric dispersion model developed by NOAA

Illness Model: Refers to our in-house simulation program that models the effects an aerosolized anthrax attack; alternatively, Anthrax Incidence Model

Incubation Period: Time between exposure to a pathogenic agent and the onset of symptoms

Incubation Stage: Bacteria or virus has been exposed to the body but symptoms are dormant

Information Gathering Interview: Interview with a subject-matter expert that only focuses on factual information pertaining to the expert's field and the response to bioterrorism

Interoperability: Several IT systems and actors functioning in coordination with one another

Investigation Phase: Set of actions within the response protocols pertaining to gathering information from actors and the scene of the detected biological pathogen; also includes initial conference calls between public health and national security actors in order to determine the threat credibility

Jurisdiction: A defined area of responsibility, specific to an organization or agency

LandScan: A geographic information system

"Likely Bioterrorism Risk": Decision from a threat credibility conference call stating that bioterrorism has likely occurred based on pathogen testing and information-gathering; prompts decision-making

MATLAB: Standing for **mat**rix **lab**oratory, a numerical computing environment that is often used for matrix calculations

Mess: Interconnected problems across a complicated society that cannot be distinguished easily through immediate analysis

Metropolitan Washington, D.C.: The immediate Washington, D.C. area and surrounding counties of the states of Virginia and Maryland

Microsoft Excel: Spreadsheet/database software created by Microsoft as part of their Office software

Microsoft Project: Project management software created by Microsoft, intended to be used in plan development

Models of Interaction: Maps of systems that display the interconnectivity and often the timing of various tasks and actors

M-file: MATLAB file containing a programmable set of commands

NAM12 Meteorological Wind Pattern Data: 12 km archived data of meteorological wind patterns in North America

National Biosurveillance Information System (NBIS): A system of agencies set up by the CDC in order to provide extensive biosurveillance, the original goal being the creation of a central fusion center

National Bioterrorism Syndromic Surveillance Demonstration Program: System that analyzes patient symptoms in search of deadly pathogen detection

National Capital Region (NCR): The region, also known as metropolitan Washington, D.C., that includes Washington, D.C., northern Virginia (Arlington, Fairfax, Loudoun, and Prince William counties), and Maryland (Frederick, Montgomery, and Prince George's counties)

National Consortium for the Study of Terrorism and Responses to Terrorism (START): Resource center and database on the University of Maryland at College Park campus associated with the DHS regarding terrorism and related research

National Electronic Disease Surveillance System (NEDSS): Online information-sharing system developed by the CDC

National Incident Management System (NIMS): Overarching response protocols outlining roles and responsibilities in the event of a natural or terrorist incident

Network-centric operations (NCO): Interoperable information sharing that coordinates technology and actors; developed via IBM

Node: A vertex on a graph

NodeXL: An open-source template program designed for the exploration of network graphs

"No Risk": Determination that an initial detection is not an act of bioterrorism

Pathogen: A biological agent

Plume Model: A model of dispersion of particles in the air, run on a computer simulation

Point of Distribution (POD): Station run by MRC volunteers and other actors to dispense prophylaxis to the general public within a jurisdiction

"Possible Bioterrorism Risk": Determination from a threat credibility conference call that national security and public health actors must continue to gather information and reconvene to make a definitive decision as to whether a detection is bioterrorism or not

Problem Situation: An unstructured description of the history and scope of a complicated problem

Prodromal Stage: The stage in a disease with the onset of early symptoms

Prophylaxis: A means of preventing disease after or before exposure (in this context, prophylactic antibiotics are the primary means)

Python: A multi-paradigm programming language known for its syntax being clear and expressive

Rapid Syndrome Validation Project (RSVP): Online surveillance and communication system for relevant actors attempting to determine whether incidents are bioterrorism

Real-time Outbreak and Disease Surveillance (RODS): Computerized surveillance system

Redundancy: Repetition of a subpath between two specific nodes within a graph

Response Delay: The delay between deciding on the solution and implementing the solution

Response Phase: Actions after decision-making related to establishing PODs, delivering supplies to said PODs, and dispensing prophylaxis to the affected population

Response Protocols: All actions related to the detection, investigation, decision-making, and response

Rich Picture: Sketch that visualizes a complicated system in a simple yet informative manner

Risk Communication: Informing and updating the public of the current risks in a location where a bioterrorism attack has been detected

Root Definition: The basic problem(s) that a system presents

Ruby Language: An object-oriented programming language similar to Python

Soft Systems Methodology (SSM): A systematic approach used to describe and understand real-world problems

Solution: A resolution determined from feasible and desirable changes that is designed to solve particular problems of the current response process

Spatio-temporal: Of or relating to space and time

Standardization: Act of applying the same set of restrictions and requirements between numerous agencies

Stochastic Model: A model of a system which involves random processes

Strategic National Stockpile (SNS): The national stockpile of prophylaxis antibiotics, vaccines, and other medical supplies allocated for large-scale medical emergencies

Subpath: A particular path in a graph between two nodes

Sub-Rich Picture: Rich picture that describes a specific phase of a complex system through a detailed sketch

Sverdlovsk: An oblast of Russia known for an anthrax attack made there in 1979

Syndromic Surveillance: A method of determining that a disease has occurred by examining the symptoms of the community

Systems-Thinking: A way of thinking concerned with the relationships among entities in a system, an integral part of SSM

TACTrend: Online compilation of Tweets that relate to public health and national security; categorized and searched by key terms

Technological Surveillance: Observing the medical well-being of an area through use of technology

TOPOFF: A planned exercise conducted by top officials to practice the response to a simulated terrorist attack

Total Hourly Sick: A simulation-determined number of individuals who are found to be sick due to anthrax germination per hour

Unified Command: Incident command shared by more than one actor

University of Maryland Institutional Review Board: Committee that approves specific research methodology that involves human subjects

Virtual USA (vUSA): Pilot project that compiles several information-sharing interphases in order to standardize communication

Walk-in Prophylaxis: Antibiotics administered immediately after screening at walk-in POD's

WMD Commission: Group led by former senators Bob Graham and Jim Talent to evaluate and suggested changes to the biological and nuclear threat security standards

WMD Center: A non-profit organization dedicated to informing the government and private sectors on the threat of bioterrorism and bolstering their preparedness

"WMD Threat Credibility Evaluation" Conference Call: Initial conference call based on detection and gathered information between public health and national security actors where such actors decide whether a threat is "No risk," "Possible Bioterrorism Risk," and "Likely Bioterrorism Risk"

World at Risk: A 2008 report of the WMD target potential and safety of the USA

yEd Graph Editor: Diagram generating software

List of References

(2004) Cities Readiness Initiative (CRI) Guidelines, Centers for Disease Control and Prevention (CDC).

(2006) National Incident Management System (NIMS) Implementation Plan, District of Columbia Emergency Management Agency.

(2008) National Response Framework, Federal Emergency Management Agency (FEMA).

(2008) SOA foundation for Network Centric Operations, IBM.

(2009) Community Assessment for Public Health Emergency Response (CASPER) Toolkit, Centers for Disease Control and Prevention (CDC).

(2009) Defense solutions: Network-centric strategies and communications technologies, IBM.

(2011) NCR Geospatial Data Exchange: Stakeholder Initiation Meeting Summary Findings, in NCR Geospatial Data Exchange, KCI Technologies, Inc.TechGlobal, Inc.Touchstone Consulting Group.

(2011) Public Health Emergency Response Guide for State, Local, and Tribal Public Health Directors, Centers for Disease Control and Prevention (CDC).

(2012) Aerosolized Anthrax Concept of Operations, U.S. Department of Health & Human Services, Public Health Emergency (PHE).

(2012) Overview of the Global Terrorism Database (GTD), START, College Park, MD.

(2010) National Consortium for the Study of Terrorism and Responses to Terrorism, START, College Park, MD.

Barnes, D. (2013) Lawmakers Reaffirm Demand for Biowatch Data. Global Security Newswire.

Bentley, T. (1993) Soft Systems Methodology. Financial Management,71, 22.

Brachman, P.S., Kaufman, A.F., and Dalldorf, F.G. (1966) Industrial Inhalational Anthrax. Bacteriological Reviews,30, 646-659.

Bravata, D.M., McDonald, K.M., Szeto, H., Smith, W.M., Rydzak, C. and Owens, D.K. (2004) A Conceptual Framework for Evaluating Information Technologies and Decision Support Systems for Bioterrorism Preparedness and Response. Medical Decision Making,24, 15.

Brookmeyer, R., Johnson, E. and Barry, S. (2003) Modeling the Incubation Period of Anthrax, Johns Hopkins University.

Bush, G.W. (2004) Homeland Security Presidential Directive 10: Biodefense for the 21st Century, in HSPD-10, Office of the Press Secretary.

Caid, L. (2003) Tucson Fire Department's MMRS Exercise: A Bioterrorism Response Plan. Public Management,85, 4.

Checkland, P. (2000) Soft Systems Methodology: A Thirty Year Retrospective in Systems Research and Behavioral Science, John Wiley & Sons, Ltd, Carnforth.

Chen, H., Zeng, D. and Yan, P. (2010) Infectious Disease Informatics: Syndromic Surveillance for Public Health and Bio-Defense, Springer, New York.

Chess, C. and Clarke, L. (2007) Facilitation of Risk Communication During the Anthrax Attacks of 2001: The Organizational Backstory. American Journal of Public Health,97, 1578-83.

Cieslak, T. and Eitzen, E. (1999) Clinical and Epidemiological Principles of Anthrax. Emerging Infectious Diseases,5, 552-555.

Dance, S. (2010) New Maryland public health lab in East Baltimore gets OK, in Baltimore Business Journal, American City Business Journals.

Cosgrove, S.E., Perl, T.M., Song, X. and Sisson, S.D. (2005) Ability of Physicians to Diagnose and Manage Illness Due to Category A Bioterrorism Agents. Archives of Internal Medicine,165, 2002-2006.

Croft, D.L., Wein, L.M. and Wilkins, A.H. (2005) Analyzing Bioterror Response Logistics: The Case of Anthrax. Management Science,51, 16.

DoS (2003) Interdiction Principles for the Proliferation Security Initiative, Bureau of International Security and Nonproliferation, Washington, DC.

ESRI (2012) ArcGIS: Mapping and Spatial Analysis for Understanding Our World, Web.

Falkenrath, R. (2010) Contrasting Federal and Local Biodefense Views, Now and in the Years Ahead, in The State of Biopreparedness: Lessons from Leaders, Proposals for Progress, University of Pittsburgh Medical Center, Washington, DC.

Fedorowicz, J. and Gogan, J.L. (2009) Reinvention of interorganizational systems: A case analysis of the diffusion of a bio-terror surveillance system. Information Systems Frontiers,12, 15.

FEMA (2008) ICS Review Material, FEMA, Web, pp. 28.

Foster, V. (2004) ESSENCE - A DoD Health Indicator Surveillance System, in 2004 Environmental Public Health Tracking Conference, Philadelphia.

Garza, A. (2010) DHS Biodefense Programs and Priorities, Now and in the Years Ahead, in The State of Biopreparedness: Lessons from Leaders, Proposals for Progress, University of Pittsburgh Medical Center, Washington, DC.

Graham, B. (2010) Strengthening the Chain of Resilience, Now and in the Years Ahead, in The State of Biopreparedness: Lessons from Leaders, Proposals for Progress, University of Pittsburgh Medical Center, Washington, DC.

Graham, B. and Talent, J. (2010) Report Card: Government Failing to Protect America from Grave Threats of WMD Proliferation and Terrorism.

Graham, B., Talent, J., Allison, G., Cleveland, R., Rademaker, S., Roemer, T., Sherman, W., Sokolski, H. and Verma, R. (2008) World at Risk: The Report of the Commission on the Prevention of WMD Proliferation and Terrorism, Vintage Books, New York.

Gray, V.C. and West, M.W. (2008) District Response Plan, Washington, D.C., pp. 28.

Hawkins, B.E., Hofacre, K.C., Wood, J. and Sparks, L. (2008) Final report on theoretical and experimental analysis of important parameters for determining the impact of a biological attack on a building, U.S. Environmental Protection Agency, Office of Research and Development, National Homeland Security Research Center, Decontamination and Consequence Management Division, Cincinnati, OH., pp. 1 online resource ([100] p.).

Hindson, B., McBride, M., Makarewicz, A., Henderer, B., Sathyam, U., Nasarabadi, S., Venkateswaran, K., Gutierrez, D., Smith, S., Metz, T. and Colston, B. (2004) Autonomous Pathogen Detection System, in Proceedings of the 2nd Joint Conference on Point Detection for Chemical and Biological Defense, Lawrence Livermore National Laboratory, City.

Holland Jr., E.J., Koh, H.K., Lurie, N. and Shahrigian, R. (2012) FY 2012 Online Performance Appendix, Department of Health and Human Services, pp. 43.

Hugh-Jones, M. and Blackburn, J. (2009) The Ecology of Bacillus Anthracis. Molecular Aspects of Medicine,30, 356-367.

Hultgren, A. (2008) Putting First Responders First, in Homeland Security S&T Stakeholders Conference West, Homeland Security Science and Technology, Los Angeles, California, pp. 18.

Hunter, N.D. (2007) “Public-Private” Health Law: Multiple Directions in Public Health. Journal of Health Care Law and Policy,10, 31.

Hupert, N., Wattson, D., Cuomo, J., Hollingsworth, E., Neukermans, K. and Xiong, W. (2009) Predicting Hospital Surge After a Large-Scale Anthrax Attack: a Model-Based Analysis of CDC's Cities Readiness Initiative Prophylaxis Recommendations. *Medical Decision Making*,29, 424-437.

Inglesby, T., O'Toole, T., Henderson, D., Bartlett, J., Ascher, M., Eitzen, E., Friedlander, A., Gerberding, J., Hauer, J., Hughes, J., McDade, J., Osterholm, M., Parker, G., Perl, T., Russell, P. and Tonat, K. (2002) Anthrax as a Biological Weapon: Updated Recommendations for Management. The Journal of the American Medical Association,287, 2236-2252.

Investigation, F.B.o. and Prevention, C.f.D.C.a. (2011) Criminal and Epidemiological Investigation Handbook, Federal Bureau of Investigation, pp. A27-A31.

Justice, U.S.D.o. (2010) Amerithrax Investigative Summary, Washington, D.C., pp. 92.

KDHE (2010) Anthrax Disease Management and Investigation Guidelines, in Kansas Disease Investigation Guidelines, The Kansas Department of Health and Environment, Topeka, Kansas, pp. 13.

Kelly, T., Tanielian, T., Don, B., Moore, M., Meade, C., Baker, J., Ccechine, G., Prine, D. and Wermuth, M. (2006) Analysis of Department of Defense Plans and Responses to Three Potential Anthrax Incidents in March 2005, RAND (Research and Development) National Defense Research Institute, Arlington.

Kirk, J. (2007) Dijkstra's Shortest Path Algorithm, MATLAB Central, www.mathworks.com, pp. M-File.

Kong, X., Wallstrom, G., Hogan, W., Zeng, D., Chen, H., Rolka, H. and Lober, B. (2008) A Temporal Extension of the Bayesian Aerosol Release Detector.

Meselson, M., Guillemin, J., Hugh-Jones, M., Langmuir, A., Popova, I., Shelokov, A. and Yampolskaya, O. (1994) The Sverdlovsk anthrax outbreak of 1979. Science,266, 1202-8.

Mingers, J. (2009) Taming Hard Problems with Soft O.R., in OR/MS Today, Institute for Operations Research and the Management Sciences.Lionheart Publishings, Inc. , Marietta, GA.

National Incident Management System, District of Columbia Homeland Security Emergency Management Agency.

Perera, D. (2013) DHS releases draft BioWatch RFP, in Fierce Homeland Security.
Prevention, C.f.D.C.a. (2010) Cities and Metropolitan Statistical Areas (MSAs) Participating in CDC's Cities Readiness Initiative (CRI), in Emergency Preparedness and Response, Centers for Disease Control and Prevention, Atlanta.

Rao, S., Mohan, K. and Atreya, C. (2010) Detection Technologies for Bacillus Anthracis: Prospects and Challenges. Journal of Microbiological Methods,82, 1-10.

Rolka, H. and O'Connor, J.C. (2011) Real-time public health biosurveillance: Systems and policy considerations. Infectious Disease Informatics and Biosurveillance: Research, Systems, and Case Studies.

Sebelius, K. (2010) HHS Views on Biopreparedness, Now and in the Years Ahead, in The State of Biopreparedness: Lessons from Leaders, Proposals for Progress, University of Pittsburgh Medical Center, Washington, DC.

Shea, D.A. and Lister, S.A. (2003) The BioWatch Program: Detection of Bioterrorism, Congressional Research Service.

Sternbach, G. (2003) The History of Anthrax. The Journal Of Emergency Medicine,24, 463-467.

Stephens, M. and Marvin, B. (2010) Recognition of Community-Acquired Anthrax: Has Anything Changed Since 2001? Military Medicine,175, 671-675.

Stoto, M.A. and Morse, L. (2008) Regionalization in Local Public Health Systems: Public Health Preparedness in the Washington Metropolitan Area. Public Health Rep,123, 13.

Trudeau, R.J. (1993) Introduction to Graph Theory, Dover Publications, Inc., New York.

Tsui, F.-C., Espino, J.U., Dato, V.M., Gesteland, P.H., Hutman, J. and Wagner, M.M. (2003) Technical Description of RODS: A Real-time Public Health Surveillance System. Journal of the American Medical Informatics Association,10, 10.

Vaughan, E. (2009) Communicating Risk of Mass Casualty Terrorism in Diverse Communities. START.

Virtual USA, National Public Safety Telecommunications Council.

Wein, L., Craft, D. and Kaplan, E. (2003) Emergency Response to an Anthrax Attack. Proceedings of the National Academy of Sciences of the United States of America,100, 4346-4351.

Williams, D. (2012) The Biodefender That Cries Wolf. Los Angeles Times.

Wyatt, P.J. (2002) Early Warning and Remediation: Minimizing the Threat of Bioterrorism. Journal of Homeland Security.

Yung, P.T., Lester, E.D., Bearman, G. and Ponce, A. (2007) An automated Front-End Monitor for Anthrax Surveillance Systems Based on the Rapid Detection of Airborne Endospores. Biotechnology and Bioengineering,98, 8.

Zilinskas, R. (1997) Iraq's Biological Weapons: The Past as Future? The Journal of American Medical Association,278, 16.