GERMS ON A PLANE: THE TRANSMISSION AND RISKS OF AIRPLANE-BORNE DISEASES

by

Nereyda L Sevilla
A Dissertation
Submitted to the
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of
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in Partial Fulfillment of
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of
Doctor of Philosophy
Biodefense

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Date: _____ Spring Semester 2017
George Mason University
Fairfax, VA

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DEDICATION

This research is dedicated to all my friends, family, and colleagues who during the years of doctoral coursework and research never stopped believing in me. Through God's strength and guidance, I am proud of what I have accomplished. Thank you all for always looking out for me.

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LIST OF ABBREVIATIONS AND SYMBOLS

Advanced Imaging Technology ..... AIT
Al Qaeda in the Islamic Maghreb ..... AQIM
Bacillus anthracis (anthrax) ..... *B. anthracis*
Basic Reproductive Ratio ..... R_o
Biological Research Advisory Board ..... BRAB
Biological Weapon ..... BW
Biological Weapons Convention ..... BWC
Centers for Disease Control and Prevention ..... CDC
Check and Report Ebola ..... CARE
Clostridium botulinum (botulism) ..... *C. botulinum*
Division of Global Migration and Quarantine ..... DGMQ
Exposed Compartment ..... E
High-Efficiency Particulate Air ..... HEPA
Immunity Loss Rate ..... α
Improvised Explosive Devices ..... IED
Incubation Rate ..... ϵ
Infectious Compartment I
Infectious Mortality Rate ..... δ
Infectious Recovery Rate ..... γ
Influenza Type H1N1 ..... H1N1
International Civil Aviation Organization ..... ICAO
International Criminal Police Organization ..... INTERPOL
International Health Regulations ..... IHR
Intravenous IV
John F Kennedy International Airport ..... JFK
National Institutes of Health ..... NIH
National Science Advisory Board for Biosecurity ..... NSABB
Pan American Health organization ..... PAHO
Person per Day (Person/Day) ..... p/d
Population Birth Rate ..... μ^*
Population Death Rate ..... μ
Recovered Compartment ..... R
Severe Acute Respiratory Syndrome ..... SARS
Spatio-Temporal Epidemiological Modeler ..... STEM
Susceptibility Compartment ..... S
Transmission Rate ..... β

Transportation Security Administration ..... TSA
Union of Soviet Socialist Republics ..... USSR
United Kingdom ..... UK
United States ..... US
Weapons of Mass Destruction ..... WMD
World Health Organization ..... WHO
World War II ..... WWII
Yersinia pestis (plague) ..... *Y. pestis*

ABSTRACT

GERMS ON A PLANE: THE TRANSMISSION AND RISKS OF AIRPLANE-BORNE DISEASES

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Purpose: This dissertation explores the role of air travel in the spread of diseases, specifically the threat of pneumonic plague as a natural outbreak or after a bioterrorist attack. **Introduction/Background:** Air travel provides new means for diseases to spread internationally at unprecedented rates. This was evident in the 2003 Severe Acute Respiratory Syndrome (SARS) pandemic that killed over 800 people across 37 countries, the 2009 Influenza H1N1 epidemic which affected over 200 million individuals, and the 2014 Ebola outbreak that killed over 11,000 people. An aircraft has a role in disease spread both as a vector and incubator. Public health interventions including travel restrictions, entry and exit procedures, quarantine and isolation, and risk communication, are some of the current methods used to contain disease outbreaks. An outbreak of pneumonic plague, which has a high mortality rate, is spread from person to person, and is endemic to the United States, may challenge the effectiveness of these public health

responses. **Methods:** This dissertation uses a mixed methods approach to evaluate the impact of aviation on the spread of infectious diseases and the effectiveness of different public health strategies. A compartment method of mathematical modeling is used to compare and contrast the spread of SARS, H1N1, and Ebola. In addition, hypothetical natural pneumonic plague outbreaks are modeled starting with 1 or 10 initial cases as well as bioterrorist attacks with *Y. pestis* that may infect 1, 10, 50, 100, or 1000 individuals to determine the potential spread over a six-month period. **Results:** All the graphical and numerical results indicate that SARS and H1N1 have a much greater impact in terms of infections and deaths than Ebola or pneumonic plague regardless of the initial number of infections. Modeling shows that the spread of pneumonic plague is minimal and should not be a major air travel concern if an individual becomes infected. Due to the rapid progression of pneumonic plague and the high likelihood of death, spread of the disease is highly unlikely to progress from the initial victims. **Conclusion:** This is the first type of research to compare, contrast, and model different diseases to determine the best scientific disease mitigation measures for the common air traveler. The threat of pneumonic plague is not from the disease, but from the potential psychological impact. To contain the outbreak of pneumonic plague, aviation and public health authorities should establish preventative infectious disease measures at airports, streamline contact procedures for ticketed passengers, expand the definition of "close contact," and conduct widespread educational programs. The measures will put in place a foundation for containing any infectious disease and ensure that a natural or intentional pneumonic plague outbreak cannot be sustained.

CHAPTER 1: INTRODUCTION

Before the age of air travel, infectious diseases historically went from local outbreak to international epidemic by ship. The risk of international spread of diseases has increased due to the advances in technology that have made global air travel a daily occurrence. The risk of disease spread increases due to the more than 4.5 billion individual air journeys made every year.[1] Figure 1 shows a visual depiction of the global dependence on air travel around the world with the routes of aircraft that can make it from one end of the Earth to another in less than 24 hours.[2] It shows how aircraft could be used as vectors to move infected individuals and spread an outbreak that may have originated on the other side of the Earth.

[1] Kirwan, D. (2009). Global Health: Current Issues, Future Trends and Foreign Policy. *Clinical Medicine, 9*, 247-253

[2] OpenFlights.org. (2012, January). Airport, airline and route data. Retrieved from Airport database: http://openflights.org/data.html

Figure 1 Global Air Travel Routes

In the 21st century, air travel provides new means for diseases to spread internationally at unprecedented rates. This was evident in the 2003 Severe Acute Respiratory Syndrome (SARS) pandemic that killed over 800 people across 37 countries, the 2009 Influenza H1N1 epidemic which affected over 200 million individuals, and the 2014 Ebola outbreak that has killed over 11,000 people. By the time travel alerts and health recommendations were announced, the diseases had already reached rampant proportions, costing thousands of lives and billions of dollars. It is incumbent on scientists to develop tools that will track and predict disease spread and identify interventions that can be executed in a timely and effective manner. Plans must be based on technical and scientific knowledge of the vectors involved and the characteristics of the emerging infectious diseases.

This dissertation will use a mixed methods approach to evaluate the impact of aviation on the spread of infectious diseases and the effectiveness of different public health strategies to mitigate an outbreak of pneumonic plague. This research will specifically outline the role of airplanes as a vector and incubator for infectious diseases. It will also examine the lessons learned within three historical disease outbreaks as a baseline—2003 SARS, 2009 H1N1, and 2014 Ebola. A literature review will be conducted from articles in the published literature, as well as from published news releases from the World Health Organization (WHO), the International Civil Aviation Organization (ICAO), the Centers for Disease Control and Prevention (CDC), as well as other organizations involved during the time of the crises. Within each of the three epidemics discussed, air travel risk factors, interventions, and outcomes will be compiled and evaluated. For the quantitative approach, a tool known as the Spatiotemporal Epidemiological Modeler (STEM), developed by IBM as an open-source program, will be used to model the baseline diseases, and then used to model a hypothetical case of pneumonic plague. The research will take previous lessons learned and apply them to pneumonic plague (in an intentional or natural form) for analysis. Pneumonic plague is the disease of focus because it is currently a threat in parts of the world and several small outbreaks have occurred in the past century. It is also a pathogen that could be aerosolized and used as a biological warfare agent.

This research will outline recommendations that will serve as the foundation for coordinated and achievable responses during a pneumonic plague outbreak. The modeling results show that pneumonic plague does not spread like SARS or H1N1.

However, the mention of a “Black Death” outbreak will cause a psychological panic that may cause unnecessary economic devastation, costly and inefficient public health responses, and an unnecessary panic of air travel. Therefore, to calm the public, authorities must effectively communicate the biological characteristics of disease spread. This will take the cooperation between scientists, public health officials, local governments, and media for a plan of constant and relevant communication. In the event of a pneumonic plague panic due to natural or intentional causes, a proper response will educate the public on the medical threats and on the risk of traveling in aircraft especially to areas of concern. Effective crisis communication is a crucial foundation and the most cost efficient and effective way of stopping panic, especially related to a deadly disease with a psychological impact like pneumonic plague. Lessons learned must be established and future programs ready to go in the event of infectious disease outbreaks and calm maintained throughout the United States. As a global leader, the United States must maintain its calm and communication to preserve the economic and health status of its citizens in order as not to affect the economic dependence of the air traveler in and out of the United States.

Recent disease outbreaks associated with air travel

In 2014, the world faced a deadly Ebola outbreak that left the confines of the immediate area due to air travel. The Ebola outbreak began in December 2013 in the Gueckedou district of Guinea, and by April had migrated to the neighboring countries of Liberia and Sierra Leone. By August, the cases rose to over 2240 with approximately

1230 deaths. In response, Liberia and Nigeria started screening people at airports and seaports, and Guinea closed its borders with Liberia and Sierra Leone.[3]

Despite these countries' containment efforts, the disease moved out of the three West African countries. In July 2014, an Ebola-infected traveler flying from Monrovia, Liberia to Lagos, Nigeria may have been the index case which started an outbreak of 19 more cases in Africa's most populous city.[4] The United States saw its first imported case in September 2014 by a man traveling back from Liberia; the traveler later died of Ebola. He, in turn, infected two nurses at the Dallas, Texas hospital where he was treated. With the disease appearing suddenly in its territory, the United States was poorly equipped with weak travel surveillance and educational policies to combat the disease as well as the growing public fear. Ebola's jump from Africa to the United States provided the third instance in the 21st century of an infectious disease migrating widely through airplane travel.

The first illustration of the impact of air travel on the rapid spread of disease occurred in 2003. A new deadly flu-like virus eventually named the Severe Acute Respiratory Syndrome (SARS) first focused attention on the issue in what was initially a localized disease. However, in a matter of weeks, SARS spread from the Guangdong province of China rapidly infecting over 10,000 individuals spanning 37 countries. SARS ultimately killed over 800 people, although none in the United States.[5] Concerned about

[3] Briand, S. (2014, September 25). The International Ebola Emergency. The New England Journal of Medicine, 1180 - 1183.
[4] Centers for Disease Control and Prevention. (July 8, 2016). CDC's Response to the 2014-2016 Ebola Epidemic - West Africa and United States. Morbidity and Mortality Weekly Report.
[5] Smith, R. (2006). Responding to Global Infectious Disease Outbreaks: Lessons from SARS on the role of risk perception, communication and management. *Social Science and Medicine, 63*, 3113-3123.

SARS spreading through air travel, the World Health Organization (WHO) issued an unprecedented series of travel alerts and recommendations including passenger temperature screenings and quarantine.[6]

The second incident occurred six years later in a form of a new and extremely contagious form of influenza. H1N1 originated in April 2009 in Mexico quickly spreading to the United States and across the world. Khan in the New England Journal of Medicine showed there was a strong correlation between international air traffic patterns and risk of H1N1 disease importation.[7] The WHO decided not to recommend travel restrictions, yet H1N1 infected over 200 million worldwide, with the United States suffering approximately 61 million cases and over 12 thousand deaths.[8]

Most of the literature on the spread of disease through air travel focuses on past incidences. The authors of past literature take the lessons learned from previous disease outbreaks to evaluate the effectiveness of current policies, and to determine if additional policies could be effective in containing future outbreaks. However, in the cases of SARS, H1N1, and Ebola, travel policies were inconsistent and ineffective. Lessons learned were not implemented and decisions based on science were lacking. Due to globalization and world dependence on airline travel, recommendations for any air travel interventions must include a scientifically-sound set of guidelines. Those guidelines may slow the spread of a disease to manageable levels. Global pandemics spread through

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[6] Wilder-Smith, A. (2003). Confronting the New Challenge in Travel Medicine: SARS. *Journal of Travel Medicine, 10*, 257-258.
[7] Khan, K. (2009). Spread of a Novel Influenza A (H1N1) Virus via Global Airline Transportation. *The New England Journal of Medicine, 361*, 212-214.
[8] Shrestha, S. (2011). Estimating the Burden of 2009 Pandemic Influenza A (H1N1) in the United States (April 2009 - April 2010). Clinical Infectious Diseases, 52(S1), S75 - S82.

airline travel require vigilance from not only local, national, and international health authorities, but also by the airlines. With comprehensive procedures, a biological threat (natural or intentional) may be slowed or contained.

Past studies have not yet answered how international travel restrictions affect the scope and severity of infectious disease outbreaks. Studies in this area are limited to retrospective case studies on specific outbreaks. The literature has some research on airline travel disseminating a disease using individuals as vectors versus the risk of in-flight transmissions. The literature also has analytical data derived from theoretical models on the impacts of restricting airline travel due to a disease outbreak. Some modeling suggests that travel restrictions are ineffective, and may have a higher economic impact than the disease itself.

This dissertation serves to bridge the gap of knowledge in the air travel dissemination of infectious diseases using pneumonic plague as a hypothetical outbreak. The research will specifically analyze the role of airplanes as a vector and incubator for infectious diseases within the context of three historical outbreaks; 2003 SARS, 2009 H1N1, and 2014 Ebola. Furthermore, the paper will evaluate the effectiveness of different public health strategies to mitigate the risk of infectious diseases spreading through the aviation system.

The objective of the research is to answer the following questions:

- How does the physical aircraft enable the spread of disease as a role of an incubator with in-flight transmissions?

- What is the role of air travel in disease transmission as a vector for humans while carrying an infectious disease?

- What is the threat of a pneumonic plague outbreak across the United States in a natural form or after an aerosolized bioterrorist attack?

- How effective are public health measures, including travel restrictions, entry and exit procedures, quarantine and isolation, educational and communication programs, in minimizing a potential outbreak of pneumonic plague?

In this dissertation, the lessons learned from the literature review were applied to a potential outbreak of pneumonic plague. Pneumonic plague was the disease of focus because it is a plausible future hypothetical case due to several factors. First, plague remains a threat throughout the world, and several small outbreaks have occurred in the past century, specifically in India. *Y. pestis* is the organism responsible for pneumonic plague. It is also a pathogen with a potential to be aerosolized and used as a biological warfare agent, and therefore merits attention. Lastly, past studies have not researched or modeled the impact of air travel on a plague outbreak, making this dissertation the first to address a potentially high-impact disease.

Methodology

This dissertation used a mixed methods approach to evaluate the impact of aviation on the spread of infectious diseases and the effectiveness of different public health strategies to mitigate an outbreak of pneumonic plague. Three case studies formulate the foundation: 1) 2003 SARS, 2) 2009 H1N1, and 3) 2014 Ebola outbreak. These case studies focus on the health policies and procedures during the outbreaks as

well as the impact that air travel had in the spread of the disease. In addition, these cases assess how previous lessons learned impacted current policy. In addition, a hypothetical scenario with pneumonic plague was modeled to determine the impact of policies and procedures on disease spread.

The biological characteristics of the diseases analyzed in this dissertation are outlined below in Table 1.

Table 1 Biological Characteristics of Diseases

	SARS	**H1N1**	**Ebola**	**Pneumonic Plague**
Family	Coronavirus (Virus)	Orthomyxoviridae (Virus)	Filoviridae (Virus)	Enterobacteriaceae (Bacteria)
Year of Outbreak	2003	2009	2014	Hypothetical
Method of Transmission	Person to person by aerosol mites & fecal-oral transmission	Person to person by respiratory fomites	Direct person to person contact through bodily fluids	Person to person by aerosol
Asymptomatic Transmission Possible	Low possibility	Yes	No	No
Transmission Potential (average # of new cases generated by each case) - R_o	2-3	1.4-3.5	1.5-2.0	1.3
Case Fatality Rate	13% <60yrs 43% >60yrs	0.01-0.3%	50-90%	50% (If Untreated, 99%)
Symptoms	Fever, General influenza-like symptoms, muscle pain	Sudden on-set fever, body aches (joints and throat), coughing, sneezing, extreme chills, fatigue, nasal congestion	Severe frontal & temporal headache, aches and pains, fever progressing to watery diarrhea, abdominal pain, nausea, vomiting	Sudden headaches, chills, malaise, and increased respiratory and heart rates progressing to cough and fever.
Treatment or Vaccine	Oseltamivir/ Supportive care/ Experimental Vaccine	Oseltamivir / Flu shot	Supportive care / Experimental Vaccines	Antibiotics effective if within 24 hours of symptoms.
Incubation Period	1-14 days	2-6 days	2-21 days	2-4 days
Duration of Illness	2-4 weeks	1-2 weeks	10-20 days	Death if untreated in 1-3 days.

Compartment theory

One of the main challenges in modeling is the choice of key epidemiological parameters. The contagiousness of the disease in the present population, the release method of the pathogen, many options in public health response, and mobility restrictions create a wide range of scenarios for which it is crucial to develop models capable of gauging the actual threat.[9] Recently increasing computational power, modern statistical methods and availability of detailed outbreak, tracing, and surveillance data are allowing the practical implementation of models to better reflect the underlying variability in the biological processes. In this dissertation, a simple compartment method of mathematical modeling was used to compare and contrast diseases of interests and to model possible interventions. Compartment models are used to illustrate disease spread using known disease parameters as well as known environmental factors while allowing for a control of basic assumptions. A compartment model for disease assumes that a population as a whole will be in separate compartments; the same person will not be in different compartments at the same time. However, factors will influence when someone moves from one compartment to another compartment.

Compartment models are used to illustrate disease spread using known disease parameters as well as known environmental factors while allowing for a control of variables. A sample compartment model is the "S" – "E" – "I" – "R" model where each person in a population, in relation to a particular disease, will be either in a state of: Susceptibility (S), Exposed (E), Infectious (I), or Recovered (R). The change in

[9] Goncalves, B. (2013). Human mobility and the worldwide impact of intentional localized highly pathogenic virus release. Scientific Reports, 3(810).

individual status from compartment to compartment may be modeled by differential equations. The compartment model used in this dissertation is visualized in Figure 2. It depicts the four compartments as well as captures the number of individuals that died due to the disease.

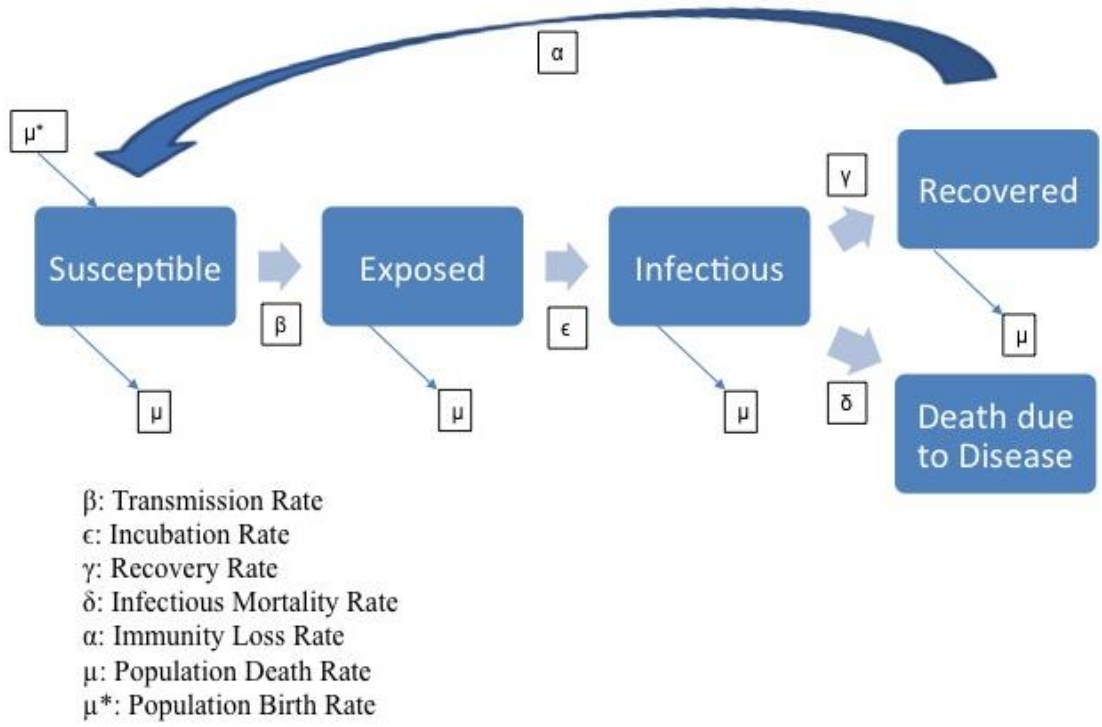

Figure 2 SEIR Compartment Model

When developing models for public health use, careful attention to the assumptions embedded within the frameworks is needed. Models provide information on the nature of the infection itself and through estimates of key parameters such as the basic reproductive ratio (R_o) make predictions about the likely outcome of alternative courses

of action. It is becoming increasingly important, therefore, that epidemiological models produce accurate quantitative predictions.[10]

Spatio-Temporal Epidemiological Modeler (STEM)

The Spatio-Temporal Epidemiological Modeler (STEM) was developed as a tool to track and predict disease spread and identify interventions that can be executed in a timely and effective manner.[11] Building on the open-source platform provided by the Eclipse Foundation, STEM is designed to analyze the global spread of infectious diseases and model the impact of public health interventions. STEM is a multi-disciplinary, collaborative modeling platform. The open-source characteristics of the system allow researchers and programmers to add, compare, refine, and validate different scenarios as well as add data based on specialties, such as population numbers, disease characteristics, geographical data, or transportation statistics. For example, an infectious disease specialist in dengue working in South America may have unique disease characteristics and population data that could be tailored into STEM. Every component of STEM is an Eclipse "Plugin" which means that each part of STEM can be independently developed, exchanged, extended, added, or removed without having to re-write computer code for the entire program. After being modified, each customized section plugs right back into the system. The more professions that add data, models, and features, the stronger the tool becomes.

[10] Wearing, H. (2005). Appropriate Models for the Management of Infectious Diseases. PLoS Medicine, 2 (7), 0621-0627.
[11] The Eclipse Foundation. (2010). Spatio-Temporal Epidemiological Modeler. Retrieved from Eclipse: http://www.eclipse.org/stem/intro.php.

STEM uses a compartment method of mathematical modeling to illustrate the spread of a disease using known disease parameters and environmental factors while allowing for the control of a host of other variables. Researchers can design disease models with known characteristics including infection rates, incubation period, and mortality rates. STEM allows these variables to be changed during the scenario to depict possible mutations in the pathogen. The STEM models can also incorporate disease vectors, such as motion of individuals, ground travel, air travel, and social gatherings that affect the transmission of an infectious disease.

STEM's model builder allows users to define new compartment models (and the corresponding equations) without the need to write any computer code. The new plugins are automatically generated by the design tool and instantly available. Compartments may be added or subtracted to match the normal characteristics of the disease. STEM provides drop-down menus so users can "plug and play" with different disease characteristics using the most appropriate compartment model. Researchers can also edit the software to customize the models to fit any scenario. These new scenarios can then be shared with the rest of the community to continue the open-source collaboration.

Essential in STEM are the depictions and interactions of different modes of transmission. STEM uses the concepts of "nodes" and "edges" to represent geographic influence on disease. In STEM, a "node" is a geographic location. An "edge" represents a relationship between two geographic locations (or nodes) such as physical adjacency (border), linked by a street or highway, or linked by air travel or train. The edge relationships are characterized by metric values that represent the weight of the

relationship. For example, the average number of people who travel between two locations (nodes) in a day and their weight value can be incorporated into the disease model computations to account for the level of contact between populations in different geographic locations. STEM characteristics eliminate the assumption of a well-mixed, uniformly distributed population highlighting geographic propagations of disease between nodes.

STEM provides the built-in data and statistics such as country and country boundaries, transportation networks, air travel, and environmental conditions for many different countries. Researchers can choose pre-populated nodes or incorporate their own geographical or transportation data. STEM can also be used to create customized graphs. This feature makes it possible, for example, to create a spatial map of the effect of quarantines or other disease interventions.

STEM is a versatile tool for modeling unrestrained disease growth as well as public health interventions such as social distancing, vaccination, quarantine, and evacuation. With all the information provided, STEM provides researchers predictions on disease incidence, the number infected, the number recovered, and fatality rates. STEM also contains built-in statistical analysis tools for comparing models and a data visualizer that can create maps of the outbreak. Data generated from the models can also be exported for analysis using other programs.

STEM is an Eclipse project originally created by IBM Research with contributors including the Federal Institute for Risk Assessment in Germany, the Johns Hopkins Bloomberg School of Public Health, and many others. The STEM open-source

community can be found at the project website: https://www.eclipse.org/stem/ and wiki: http://wiki.eclipse.org/index.php/STEM. Anyone can join the STEM community, participate in the monthly phone calls, add data to the program, and share lessons learned. Scientists and public health officials are welcome to contribute to STEM, report bugs, or request new features or scenarios. STEM can be downloaded to any computer running Windows, Mac OS X, or other operating systems. The STEM website offers full download links, tutorials, installation guides, and YouTube video tutorials in English, Hebrew, Japanese, and Spanish. STEM also has many sample projects that researchers from around the world have shared and made available for download. These scenarios include the recent 2014 Ebola epidemic, dengue fever, avian influenza, malaria, H1N1, and food-borne diseases. The STEM wiki page has a full list of STEM resources and publications that showcase disease models. Baldassi concluded in "Testing the accuracy ratio of the Spatio-Temporal Epidemiological Modeler (STEM) through Ebola haemorrhagic fever outbreaks" that "if the epidemiological features of a specific contagious disease are already known, STEM software could be a useful tool for understanding, with a high level of accuracy, how the outbreak will spread."[12] Further, Edlund stated in "Comparing three basic models for seasonal influenza" that STEM provides "support for computational experiments making it an excellent starting point" for modeling the spread of infectious diseases.[13]

[12] Baldassi, F. (2016, May). Testing the accuracy ratio of the Spatio-Temporal Epidemiological Modeler (STEM) through Ebola haemorrhagic fever outbreaks. *Epidemiology and Infection*, 1463-1472.
[13] Edlund, S. (2011). Comparing three basic models for seasonal influenza. Epidemics, 135-142.

This dissertation used the STEM model in the confines of compartment theory to model 3 hypothetical disease outbreaks, specifically SARS, H1N1, and Ebola. The models forecast the natural flow of disease with air travel impact in a scenario where 1 or 10 infected individuals arrived at JFK International Airport near New York City. The models demonstrate how a single individual may or may not start an outbreak, and the possible outcomes of multiple individuals arriving from an infected country or getting infected in the aircraft or in the airport through close contact.

STEM was also used to model a hypothetical case of pneumonic plague. The same scenarios, geographical parameters, and transportation baselines modeled for the SARS, H1N1, and Ebola outbreaks were also used to model the spread of pneumonic plague. In modeling pneumonic plague, and applying the lessons of real-world outbreaks, public health officials may make informed decisions as to the best interventions and communication methods should another pneumonic plague outbreak occur. A plan of action is essential to ensure disease containment, calm the public, and limit economic damage.

Pneumonic plague: the next outbreak of concern

Plague has been described as one of the world's worst diseases causing at least three human pandemics: 1) the 6th century Justinian plague, which caused almost 100 million deaths; 2) the "Black Death" which occurred in the Middle Ages between the 14th

and 17th century, and killed one-third of Europe's population; and 3) the most recent pandemic of 1895-1930, which killed approximately 12 million people, mostly in India.[14]

Today plague incidences still arise worldwide and are responsible for approximately 200-4500 human cases including 30-200 deaths reported to the WHO annually.[15] Figure 3 has a visual depiction of the reported cases of plague from 2000-2009.[16]

[14] Kool, J. (2005). Risk of Person-to-Person Transmission of Pneumonic Plague. Clinical Infectious Diseases, 40, 1166-1172.
[15] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.
[16] Centers for Disease Control and Prevention. (2013, April 23). Maps and Statistics. Retrieved from Plague: http://www.cdc.gov/plague/maps/index.html.

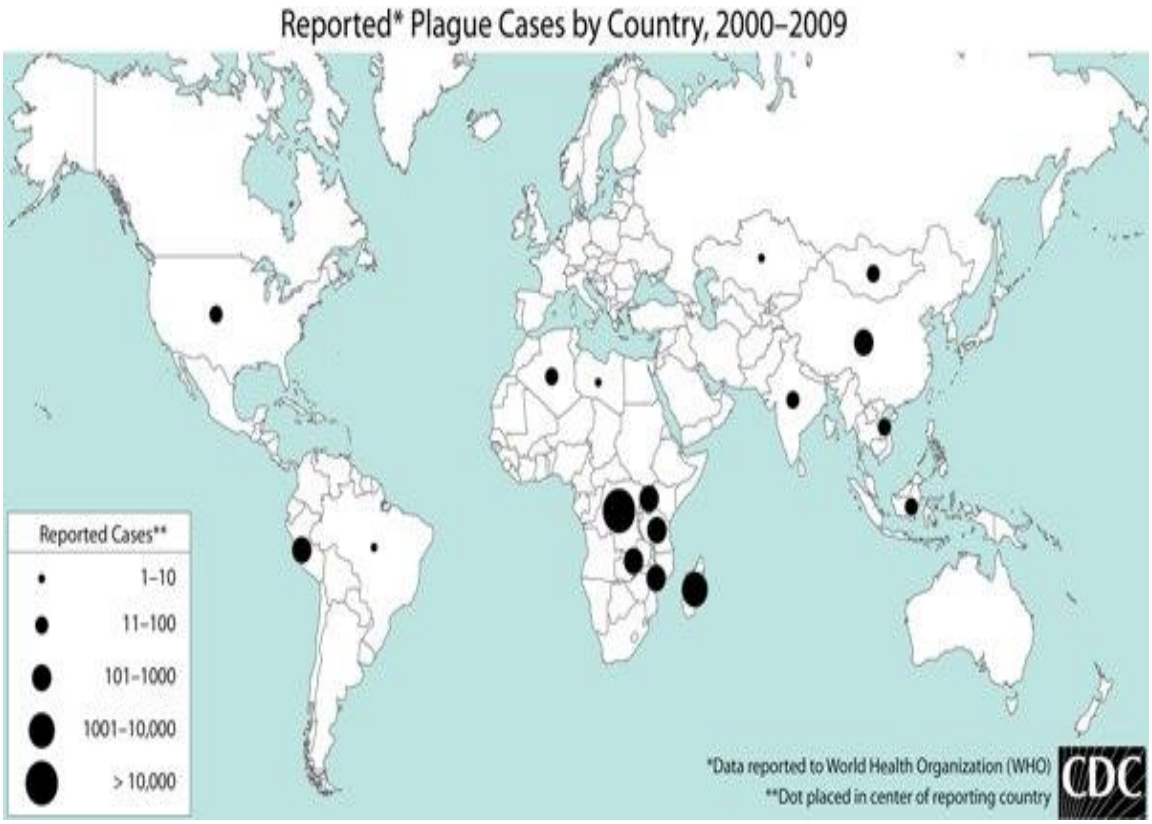

Figure 3 Plague Around the World

Plague is a rodent-associated, flea-borne zoonosis caused by the gram-negative bacterium *Yersinia pestis*.[17] *Y. pestis* is a rod-shaped, non-motile, non-sporulating, bacterium of the family Enterobacteriaceae. Humans typically develop disease through contact with infected rodents or more commonly their fleas. The biting fleas can transmit bacteria to humans, who then develop the bubonic form of plague.[18] The bubonic form may progress to the septicemic and/or pneumonic forms. The pneumonic form of plague

[17] Gage, K. (2005). Natural History of Plague: Perspectives from More than a Century of Research. Annual Review of Entomology, 50, 505-528.
[18] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.

may then be transmitted from person to person. The natural cycles of plague from zoonotic phase to human transmission are outlined in Figure 4[19].

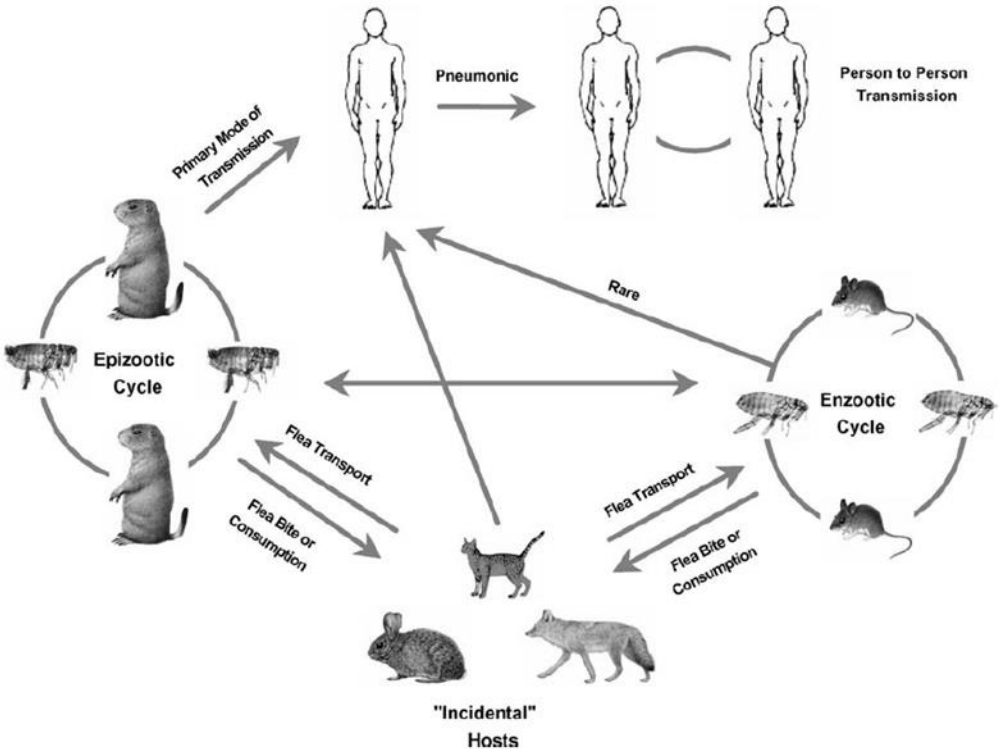

Figure 4 Natural Cycles of Plague

Bubonic plague does not spread from person to person. However, pneumonic plague develops when the bacterium reaches the lungs and causes a secondary infection.[20] Pneumonic plague is the only form of plague that can be transmitted from human to human. The disease resulting from direct infection of the airways is usually

[19] Gage, K. (2005). Natural History of Plague: Perspectives from More than a Century of Research. Annual Review of Entomology, 50, 505-528.
[20] Kool, J. (2005). Risk of Person-to-Person Transmission of Pneumonic Plague. Clinical Infectious Diseases, 40, 1166-1172.

called primary pneumonic plague. This form would also occur after an intentional release of aerosolized *Y. pestis*. Before antibiotics were available, the mortality associated with pneumonic plague was virtually 100%, with most infected people succumbing 1–3 days after onset of the first symptoms. Antibiotics such as aminoglycosides and tetracyclines significantly reduce mortality if they are administered within 24 hours after the onset of disease.[21] All human populations are susceptible, and recovery is followed by temporary immunity.

Pneumonic plague would be the predominate form of disease expected after purposeful aerosol dissemination of the pathogen. This research will describe key features of pneumonic plague, including its clinical features, current endemic status, and possibility of disease spread, either from a natural outbreak or after a bioterrorist attack.

Clinical features and medical management

The vast majority of the 1 to 40 human cases reported annually in the US are from the desert southwest, where plague is endemic in rural rodent populations. Figure 5 has a visual depiction of the reported cases of human plague in the United States from 1970-2012; where as Figure 6 shows the reported human plague cases in the United States by year[22]. Most naturally occurring human cases in the US are bubonic (85%), followed by

[21] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.
[22] Centers for Disease Control and Prevention. (2013, April 23). Maps and Statistics. Retrieved from Plague: http://www.cdc.gov/plague/maps/index.html.

primary septicemic (13%), then primary pneumonic (1-2%) disease.[23] In the United States, the plague season is from February through August.[24]

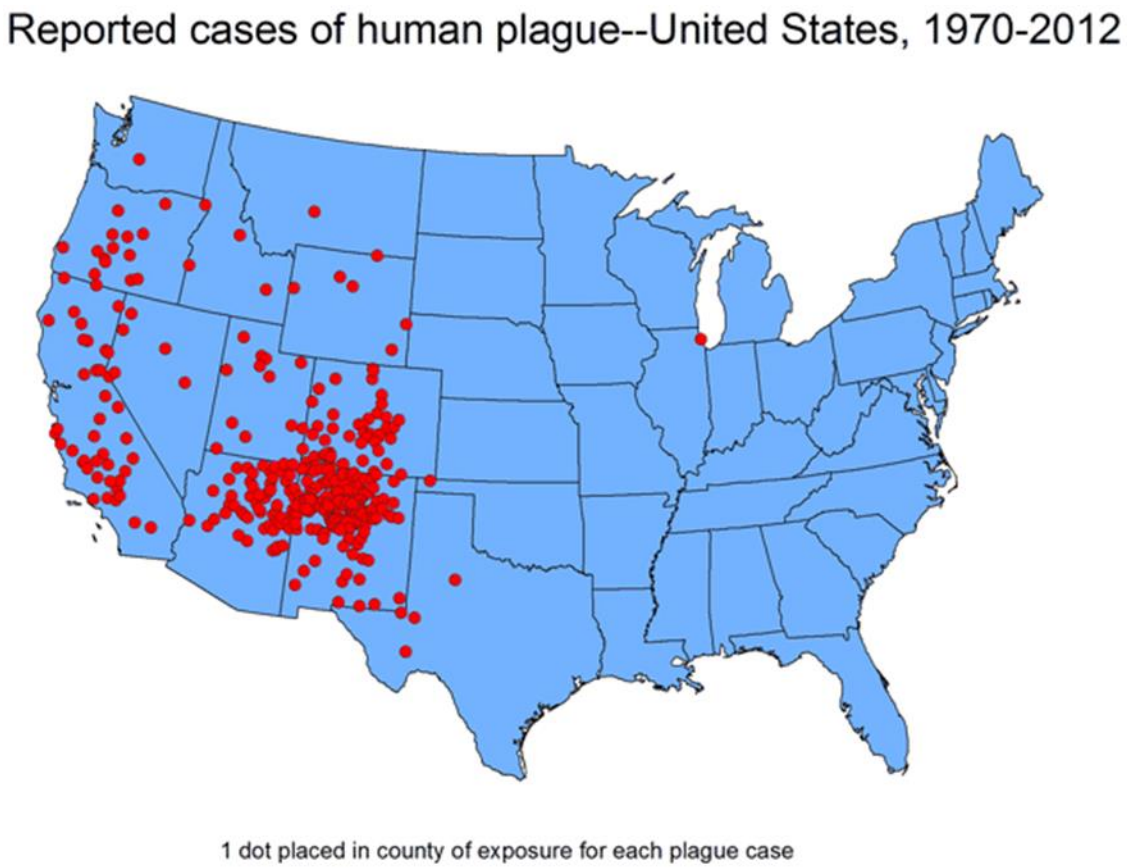

Figure 5 Human Cases of Plague in the United States by Region

[23] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.
[24] Butler, T. (2009). Plague into the 21st Century. *Clinical Infectious Diseases, 49*, 736-742.

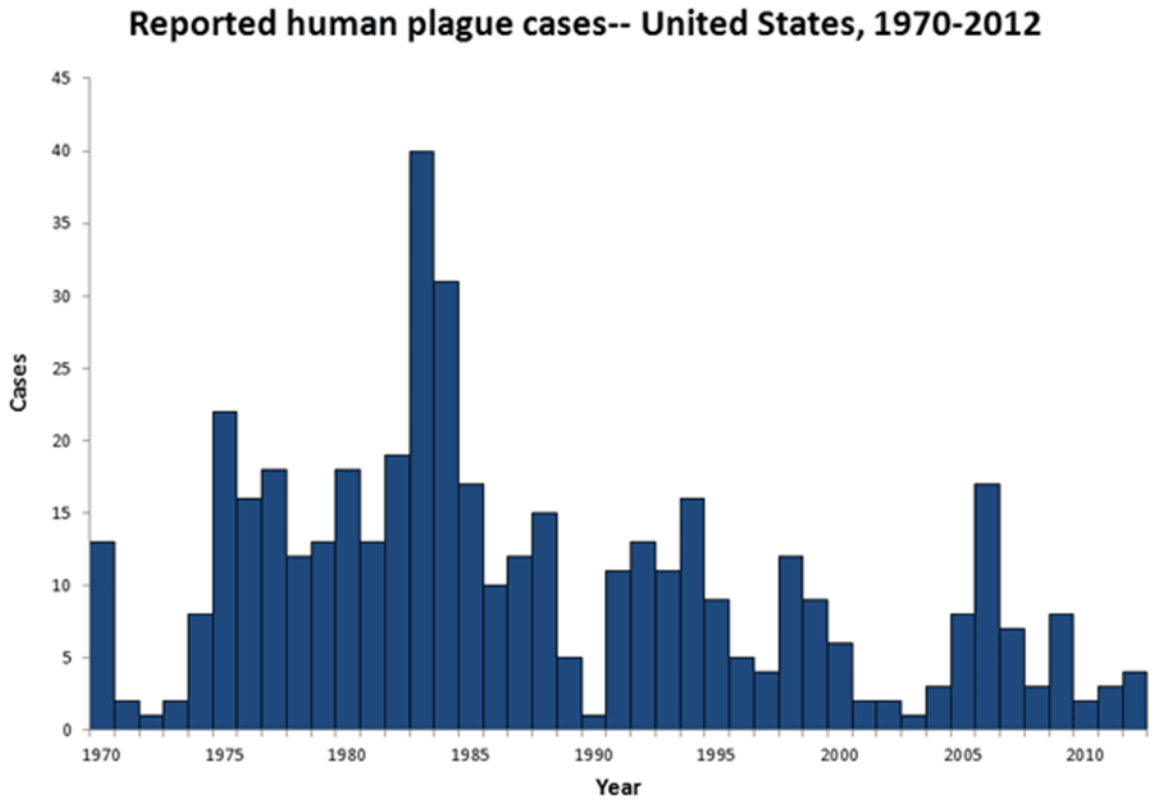

Figure 6 Chart of Human Plague Cases in the United States by Year

Secondary pneumonic plague has been a complication in 12% of bubonic cases in the US over the past 50 years. 20% of human plague cases resulting from exposure to plague-infected domestic cats in the US in recent decades were presented as primary pneumonic plague; 25% of these human cases were in veterinarians or their assistants. Person-to-person spread of pneumonic plague has not occurred in the US since 1925. The first signs of illness include high fever, chills, headache, and malaise followed within 24 hours by cough and bloody sputum. Gastrointestinal symptoms, including nausea, vomiting, diarrhea, and abdominal pain, may be present. Pneumonia progresses rapidly and terminates with respiratory failure and circulatory collapse. The case fatality rate for

pneumonic plague patients in the US is approximately 50%. If untreated, the case fatality rate for pneumonic plague is nearly 100%. In the US, in the past 50 years, 4 of the 7 pneumonic plague patients (57%) died.[25]

From the data available on past pneumonic plague epidemics, the average secondary infection rate is 1.3 cases per primary case (range 0 to 6). Transmission has been greatest under crowded, cold and humid conditions. The majority of secondary cases have been in caregivers at home (80%) or medical professionals (14%) after close contact with the primary cases.[26] Primary pneumonic plague transmission usually results from close contact within 2 meters with a person or animal expelling fine droplets of *Y. pestis*.[27]

Medical management of pneumonic plague

Prompt initiation of appropriate antibiotics is paramount for reducing mortality; this is especially true in primary pneumonic plague, for which case fatality rates approach 100% if adequate therapy is not initiated within 24 hours of onset of symptoms. Initial treatment for systemic disease caused by *Y. pestis* includes antibiotics.[28] Streptomycin has historically been the drug of choice for plague and is the only antibiotic approved by the FDA for the treatment of plague. However, because it may not be readily available

[25] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.
[26] Ibid.
[27] Joshi, K. (2009). Epidemiological features of pneumonic plague outbreak in Himachal Pradesh, India. Transactions of the Royal Society of Tropical Medicine and Hygiene(103), 455-460.
[28] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.

immediately after a large-scale bio-warfare attack, gentamicin and other alternative drugs may be used, including doxycycline and ciprofloxacin.[29]

Intravenous (IV) antibiotics can be switched to oral as the improvement in the patient's clinical course dictates, to complete at least 10 to 14 total days of therapy. Patients with uncomplicated bubonic plague often demonstrate resolution of fever and other systemic symptoms within 3-5 days while more complicated bubonic, septicemic, and pneumonic plague often results in extended hospital stays.[30]

Prophylaxis

No vaccine is currently available for prophylaxis of plague. A licensed, killed whole cell vaccine was available in the US from 1946 until 1998. It offered protection against bubonic plague, but was not effective against aerosolized *Y. pestis*.[31]

No antibiotics are licensed by the FDA for use before exposure to plague. Face-to-face contacts of patients with pneumonic plague or persons possibly exposed to a plague aerosol are given antibiotic prophylaxis for 7 days or the duration of risk of exposure plus 7 days. If fever or cough occurs in these individuals, a full treatment course with antibiotics is started.[32]

[29] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.
[30] Ibid.
[31] Ibid.
[32] Ibid.

Bioterrorism: intentional use of *Y. pestis*

The threat of biological weapons (BW) has been part of history since the Scythian archers used arrows dipped in blood and manure from decomposing bodies in 400 BC.[33] The question remains: "Why would terrorists use biological weapons versus traditional conventional weapons in this modern society?" While the late 20th century had its nuclear Cold War, the start of the 21st century is marked by "unconventional warfare." That new warfare goes beyond conventional violence, but one that takes the horror of death and merges it with the panic of biological weapons. The United States and many other nations have banned together in support of international WMD non-proliferation treaties, specifically the Biological Weapons Convention (BWC), currently ratified by 178 parties.[34] In ratifying the BWC, states assure each other to…"exclude completely the possibility of bacteriological (biological) agents and toxins being used as weapons, convinced that such use would be repugnant to the conscience of mankind and that no effort should be spared to minimize this risk."[35]

Before the ratification of the BWC, the United States, the United Kingdom, Japan, and Russia had its history of trying to develop and test *Y. pestis* as part of their country's biological weapons program as described below. Though *Y. pestis* was minimally used prior to 1939, WWII became a catalyst of biological weapons programs around the world specifically the main countries at war. After 1945, the biological weapons programs

[33] Smart, J. (1997). History of Chemical and Biological Warfare: An American perspective. In US Army, *Medical Aspects of Chemical and Biological Warfare.* Washington DC: Borden Institute.
[34] The United Nations Office at Geneva. (n.d.). *About the Biological Weapons Convention*. Retrieved 2017, from The Biological Weapons Convention: http://www.unog.ch/80256EE600585943/(httpPages)/77CF2516DDC5DCF5C1257E520032EF67?OpenDocument.
[35] Ibid.

continued until the ratification of the BWC, though today the nations must not only contend with nation-states but possible non-state international and domestic terror groups that may use biological weapons as part of their terror arsenal.

United States, Japanese, and Russian history in *Y. pestis* BW research

The earliest known use of *Yersinia pestis* used as a biological weapon comes from the 14th century when Tartar forces heaved plague-infected corpses into the walled city of Caffa in 1346 and then much later in the 18th century when Russian forces used plague-infected bodies against Sweden.[36] However, the modern era research into plague as a biological warfare agent begins around the World War II era by the Soviet Union, Japanese, and the United States.

In the 1930's, the United States Army's position on the use of biological weapons was formulated and argued by Major Leon Fox who published his views about the downfall of biological weapons.[37] For the case of plague, Fox stated that "the use of bubonic plague today against a field force, when the forces are actually in contact, is unthinkable for the simple reason that the epidemic could not be controlled. The torch once set off might destroy friend and foe alike and would therefore prove of no value as a military weapon."[38] However, he did acknowledge that the plague could still be used to harass civil populations especially with airplanes flying low to drop recently infected rats.[39] This article was published in March 1933 under the title "Bacterial Warfare: The Use of Biologic Agents in Warfare." The article was translated into Japanese and read by

[36] Abbott, R. (2012). Plague. National Wildlife Health Center, US Department of the Interior. Reston, VA: US Geological Survey.
[37] Regis, E. (1999). *The Biology of Doom.* New York: Henry Holt and Company.
[38] Ibid.
[39] Ibid.

Dr. Ishii Shiro of the Imperial Japanese Army who had a contrary view on the use of biological weapons.[40]

Japan inflicted some of the worst atrocities using biological weapons against humans. The Japanese biological warfare program fell under the command of Colonel Ishii Shiro who was a PhD microbiologist and medical doctor.[41] His inspiration was the 1925 Geneva Protocol that outlawed biowarfare claiming that "if it was worth banning, it must be a potentially valuable weapon."[42] During the 1930s, Dr. Ishii built 19 facilities outside of Japan to conduct bioweapon experimentations as he did not want to subject the Japanese people to the potential agents.[43] Ping Fan near Harbin, Manchuria, China was the most infamous of the Japanese facilities directly responsible for over 3,000 deaths of political prisoners, common criminals, and other rounded-up innocents.[44] These facilities worked around the clock, 365 days a year from 1939 to the end of World War II to produce pathogens for human and environmental experimentations.[45]

The Japanese did have some success with *Y. pestis* testing bombs designed to disseminate plague-infested fleas. In October 1940, a lone Japanese plane circled the town of Chuhsien south of Shanghai, China, and dropped a cargo of wheat grains, rice, and plague-infested fleas. Thirty-eight days later an epidemic of bubonic plague broke out lasting for 24 days causing 21 deaths, in an area that had never experienced plague

[40] Regis, E. (1999). *The Biology of Doom.* New York: Henry Holt and Company.
[41] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.
[42] Ibid.
[43] Ibid.
[44] Ibid.
[45] Harris, S. (1994). *Factories of Death.* New York: Routledge.

before.[46] The same scenario was repeated in the port city of Ningbo, China where a Japanese plane also dropped a large amount of grains and fleas; the plague epidemic lasted 34 days and claimed 100 lives.[47]

The United States established a Committee on Biological Warfare on 18 November 1941 in the middle of World War II after the Army Surgeon General Office petitioned for more emphasis on biological warfare in direct opposition to Maj Fox's 1933 views.[48] Nine days after the Committee on Biological Warfare met for the first time, the US Army received its first reports of the Japanese bubonic plague attacks.[49] In June 1942, the Committee issued a report stating that in regards to biological warfare, "the best defense is offense and the threat of offense."[50] The United States ended World War II by dropping the nuclear bomb and no counter-offensive was used against or with biological weapons. However, the United States continued its pursuit of biological weapons from 1945 primarily because it believed the Union of Soviet Socialist Republics (USSR) would use any type of weapon and the US should be prepared to defend and possibly retaliate.[51]

After 1945, the United States, United Kingdom, and Canada created tripartite cooperative arrangements for biological weapons research. In a series of bioweapon sea trials, the cooperation was an effort to determine the threat of biological weapons in

[46] Regis, E. (1999). *The Biology of Doom.* New York: Henry Holt and Company.
[47] Ibid.
[48] Ibid.
[49] Ibid.
[50] Ibid.
[51] Moon, J. (2006). The US Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 9-46). Cambridge: Harvard University Press.

terms of agents, delivery systems, and possible defensive measures.[52] Canadians themselves never possessed biological weapons within their country, but Canadian scientists did play a role in the cooperative agreement between 1939 and 1969.[53] The British Air Force's perspective of biological weapons held that it was by far "the most economical" method of waging war.[54] A British-led effort on the testing of plague occurred in April 1952 as part of Operation Cauldron off the coast of the Isle of Lewis with monkeys and guinea pigs on a floating pontoon. In August, two joint memos praised the efficiency and simplicity of the techniques; however, they indicated that more testing was needed to gather more information regarding weathering of organisms and safety distances.[55] Overall, the test of plague had been considered a failure, reversing an earlier portrayal of success.[56]

On 25 November 1969, President Richard Nixon announced that he was unilaterally renouncing the biological warfare program and the US would confine its biological research to "defensive measures such as immunization and safety measures."[57] Nixon presented this renunciation as an "initiative toward peace."[58] American scientists, before the 1969 shutdown, were never able to grow plague in bulk for weaponized purposes.[59] In 1975, the US ratified the Biological Weapons Convention (BWC) and the

[52] Balmer, B. (2001). *Britain and Biological Warfare.* New York: Palgrave.
[53] Avery, D. (2006). The Canadian Biological Weapons Program and the Tripartite Alliance. In M. Wheelis, Deadly Cultures (pp. 84-107). Cambridge: Harvard University Press.
[54] Balmer, B. (2001). Britain and Biological Warfare. New York: Palgrave.
[55] Ibid.
[56] Balmer, B. (2006). The UK Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 47-83). Cambridge: Harvard University Press.
[57] Moon, J. (2006). The US Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 9-46). Cambridge: Harvard University Press.
[58] Ibid.
[59] Orent, W. (2004). Plague. New York: Free Press.

Geneva Protocol which is the "Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction."[60] This marked the end of any offensive biological weapons research for the US. The British biological program came to a close around 1977 with the dissolution of the BRAB, the Biological Research Advisory Board.[61] In the 1980s and 1990, Britain considered biological threats still a possibility, and in 2001 the government maintained the defense research establishments now publicly known as the Defence Science and Technology Laboratory.[62] The US has in place "Institutional Biosafety Communities" to oversee potential research into biological pathogens and, in 2004, created the National Science Advisory Board for Biosecurity (NSABB) at the National Institutes of Health (NIH) to review possible dual-use research of biological pathogens.[63]

The USSR had a limited biological program during World War II. The Soviets expanded their offensive biological warfare program into the 1970s, 80s, and 90s. Notable defectors provided information on the Soviet program including Kanatjan Baizakovich Alibekov and Vladimir Artemovich Pasechnik. The defectors claim that the Soviet Union also conducted human plague experiments like Dr. Ishii did in Japan. The USSR used political and Japanese prisoners of war who were confined to a tent with plague-infested rats until bitten, thus infecting them with plague. Unfortunately, when the

[60] US Department of State. (1975, 26 March). *Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction (BWC).* Retrieved from Current Treaties and Agreements: https://www.state.gov/t/isn/4718.htm.
[61] Balmer, B. (2006). The UK Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 47-83). Cambridge: Harvard University Press.
[62] Ibid.
[63] Koblentz, G. (2009). *Living Weapons.* Ithaca and London: Cornell University Press.

prisoners escaped, they sparked an epidemic killing between 3000 and 5000 Mongols.[64] Dr. Pasechnik relayed information about Leningrad's All-Union Institute of Highly Pure Biological Preparations that focused on weaponizing *Yersinia pestis*.[65] By 1987, the facility reportedly had a manufacturing capacity of approximately 200 kilograms per week.[66] Dr. Alibekov (now known in the US as Dr. Kenneth Alibek) revealed that by 1991 the Russians were testing the dissemination of genetically engineered antibiotic – resistant plague.[67] Dr. Alibek stated that the Russians were able to transfer the gene for myelin toxin to *Y. pestis*, and though a weapon was never created before the collapse of the USSR, it led the way for further research on bacteria-toxin combinations.[68] Alibek stated Russians had a goal to develop a plague strain resistant to approximately 10 antibiotics.[69] Dr. Alibek in his book, "Biohazard," further detailed that the Russians persevered into growing plague in a wide range of temperatures and media.[70] Alibek claims that the objective was to fill warheads with plague and the cities of London, Los Angeles, New York, and Washington DC had been identified to be the attack targets for the weapons.[71]

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[64] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.
[65] Hart, J. (2006). The Soviet Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 132-156). Cambridge: Harvard University Press.
[66] Ibid.
[67] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.
[68] Alibek, K. (1999). Biohazard. New York: Random House.
[69] Hart, J. (2006). The Soviet Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 132-156). Cambridge: Harvard University Press.
[70] Alibek, K. (1999). Biohazard. New York: Random House.
[71] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.

The USSR officially ratified the BWC in 1975.[72] However, when President Boris Yeltsin took over Russia in 1992, he confirmed the Russian offensive biological warfare program.[73] Though Yeltsin stated that he would convert the program for civilian use, Dr. Alibek claimed the biological warfare program stayed open through 1999.[74] The United States continues to believe that the Russians have not completely shut down their offensive BW program. On 4 March 2003, a US Department of State official testified to Congress that "we believe, based on available evidence, that Russia continues to maintain an offensive biological weapons program," and in 2004, the US Department of Defense estimated that approximately 40 institutes that were formerly part of the Soviet BW program still exists.[75]

The United States and Japan have a history of conducting offensive and defensive biological weapons research. Since World War II, Russia, as well as the former Soviet Union are suspected of being in direct violation of the Biological Weapons Convention. However, the BWC does not cover domestic or international terrorism and must use protection policies to deter these illicit acts. Bruce Hoffman in his book "Inside Terrorism," further defines terrorism as "the deliberate creation and exploitation of fear through violence or the threat of violence in the pursuit of political change."[76] These acts may be internal within a country or against individuals of other countries. In the case of

[72] Hart, J. (2006). The Soviet Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 132-156). Cambridge: Harvard University Press.
[73] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.
[74] Ibid.
[75] Hart, J. (2006). The Soviet Biological Weapons Program. In M. Wheelis, *Deadly Cultures* (pp. 132-156). Cambridge: Harvard University Press.
[76] Hoffman, B. (2006). *Inside Terrorism.* New York, NY: Columbia University Press.

terrorism, the US must be prepared to act against radical individuals who use bioterrorism to try to make a political point.

Larry Wayne Harris: domestic bioterrorism with *Y. pestis*

Pneumonic plague would be the predominate form of disease expected after purposeful aerosol dissemination. The domestic terrorist potential of plague was highlighted in 1995 when Larry Wayne Harris was arrested in Ohio for the illicit procurement of a *Y. pestis* culture through the mail. Six weeks after the March 1995 sarin attacks in Tokyo, Mr. Harris, a member of the Aryan Nations white supremacist group, ordered three vials of freeze-dried plague causing pathogen from the American Type Culture Collection (ATCC).[77]

J. Stern provided a detailed account of Mr. Larry Harris's procurement of *Yersinia pestis* and his arrest in his book chapter "Larry Wayne Harris" inside of J Tucker's book "Toxic Terror."[78] In the chapter, it describes how Larry Harris at the time was employed by Superior Laboratories in Columbus, Ohio to test drinking water samples and inspect septic systems. Harris told several colleagues that he wanted to order some *Y. pestis* for defensive research. When Harris called ATCC to inquire about the status of his delivery, Harris' suspicious manner prompted the ATCC technician to notify the CDC. Harris told the CDC he was conducting biomedical research to counteract an "imminent invasion from Iraq of supergerm-carrying rats."[79]

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[77] Barnaby, W. (2002). The Plague Makers: The Secret World of Biological Warfare (3rd ed.). New York: The Continuum International Publishing Group, Inc.
[78] Tucker, J. (2000). *Toxic Terror.* Cambridge, MA: Belfer Center for Science and International Affairs.
[79] Stern, J. (2000). Larry Wayne Harris (1998). In J. Tucker, *Toxic Terror Assessing Terrorist Use of Chemical and Biological Weapons* (pp. 227-246). Cambridge: Belfer Center for Science and International Affairs.

Public health officials involved in the case claim that it made them realize how poorly prepared they were for a bioterrorist incident. First responders were able to arrest Harris and recover the plague without incident. While the police were inspecting the home, they found weapons and explosives in addition to the plague bacteria.[80] Because of Harris's affiliation with the Aryan Nations, the case was considered a possible act of domestic terrorism.[81] Mr. Harris pled to a single count of wire fraud for falsifying information in his request for the *Y. pestis*. Harris was placed on probation for eighteen months, ordered to complete 200 hours of community service, and pay a $50 fee.[82]

After his arrest and in subsequent interviews, Harris claimed that he isolated plague bacteria from cow droppings and said that it took him "fourteen days to recover bubonic plague."[83] According to federal prosecutors, Harris told an unidentified source that he was planning an attack on the New York subway with bubonic plague, using the same technique that the Army had employed in the 1960's. In that scenario, the Army disseminated simulant bacteria by dropping light bulbs filled with simulant bacteria through ventilated grates or onto the track beds as trains entered or departed a New York Subway station.[84] Harris reportedly predicted that hundreds of thousands of people would

[80] Stern, J. (2000). Larry Wayne Harris (1998). In J. Tucker, *Toxic Terror Assessing Terrorist Use of Chemical and Biological Weapons* (pp. 227-246). Cambridge: Belfer Center for Science and International Affairs.
[81] Ibid.
[82] Ibid.
[83] Ibid.
[84] Ibid.

die making Americans more aware of the dangers they face. Harris had a self-appointed mission to teach citizens how to protect themselves in the event of a biological attack.[85]

Since there were no laws at the time preventing the original request, this incident led to the creation of the "Select Agents and Toxins Regulations" to document the access and location of dangerous pathogens.[86] *Yersinia pestis* remains on the list as a Health and Human Services Tier 1 Select Agent.[87] However, even the arrest of Larry Wayne Harris, and the creation of the Select Agents and Toxins Regulations did not stop Mr. Harris from perusing biological agents. The regulations do not cover biological agents isolated from nature or individuals who are conducting research with biological agents they already possess. Harris emphasized in an interview that the regulations will not preclude amateur scientists or terrorists from acquiring biological weapons.[88] Harris commented that "the only thing the law has toughened up is the shipping requirements. He reflected back into his arrest and stated that "that was just an irritation for me. I've continued my research."[89]

The case of Larry Wayne Harris did emphasize a continuous need to be vigilant of domestic attempts to use *Y. pestis* in a bioterrorist attack. Though Mr. Harris was unsuccessful, ancient history and recent cases show that plague may still be a potential

[85] Stern, J. (2000). Larry Wayne Harris (1998). In J. Tucker, Toxic Terror Assessing Terrorist Use of Chemical and Biological Weapons (pp. 227-246). Cambridge: Belfer Center for Science and International Affairs.
[86] American Association for the Advancement of Science. (2013). Bridging Science and Security for Biological Research. *Implementing the Revised Select Agents and Toxins Regulations: Proceeding from the Meeting, 22-23 April*, (pp. 1-30). Washington D.C.
[87] Centers for Disease Control and Prevention. (2014). *Federal Select Agent Program*. Retrieved from Select Agents and Toxins List: http://www.selectagents.gov/SelectAgentsandToxinsList.html
[88] Stern, J. (2000). Larry Wayne Harris (1998). In J. Tucker, Toxic Terror Assessing Terrorist Use of Chemical and Biological Weapons (pp. 227-246). Cambridge: Belfer Center for Science and International Affairs.
[89] Ibid.

threat and it continues to be a pathogen of interest. Since pneumonic plague has not been eradicated and cases do occur in many parts of the world and within the United States, technology may continue to expand to weaponize *Y. pestis.* Recently, other international terrorist groups have also found an interest in using *Y. pestis* as an agent of terror as described below.

Al Qaeda and ISIS: international terrorist interest in *Y. pestis*

In 1998, al Qaeda, under Osama bin Laden declared it a "religious duty" to acquire nuclear, biological, and chemical weapons.[90] Al Qaeda's BW program was headed by Ayman al-Zawahiri, the second-ranking official in al Qaeda. Zawahiri was attracted to biological weapons because he believed that "these weapons were as lethal as nuclear weapons, that they could be produced simply, that the delayed effects of a biological attack would increase the number of casualties, and that defending against these weapons was very difficult."[91] After invading Afghanistan, the US discovered scientific articles on the isolation, purification, and production of bacterial pathogens including *B. anthracis, C. botulinum*, and *Y. pestis* at an al Qaeda training camp near a captured BW laboratory.[92] The United States has captured or killed most of the known participants in the al Qaeda's BW program; however, there was concern that al Qaeda trained or inspired cells could continue to pursue bioweapons separately including plague.[93]

[90] Koblentz, G. (2009). *Living Weapons.* Ithaca and London: Cornell University Press.
[91] Ibid.
[92] Ibid.
[93] Ibid.

Since 2000, there have been warnings of interest in using plague as a bioterror weapon. There is a wide availability of recipes in al Qaeda training manuals and online jihadist chat rooms that allegedly describe how to produce *Y. pestis*.[94] In a 15-page Arabic language document posted on-line in 2005 entitled "Biological Weapons," al Qaeda describes how the plague could be made into a biological weapon if a small supply of the bacterium could be acquired. This guide drew on lessons learned from WWII to extract microbes from infected rat's blood and used with an aerosol delivery system.[95] However, experts believe that these recipes are "rudimentary, lack important details or include incorrect information, and are unsuited for producing pathogens or toxins of sufficient quantity or quality to cause mass casualties."[96]

On 19 January 2009, the British tabloid Sun published that at least 40 members of Al Qaeda in the Islamic Maghreb (AQIM) had died of the plague in a training camp located in Tizi Ouzou, Algeria.[97] The tabloid speculated that this incident could be the result of an accident linked to the production of *Y. pestis*.[98] However, further analysis from researchers suggests that AQIM did not have the facilities or knowledge for the production of plague weapons and that the deaths were likely caused by a natural outbreak fueled by unsanitary conditions within the training camps.[99] The analyses of the al Qaeda's manuals indicate that instructions to weaponize *Y. pestis* were valid but very

[94] Koblentz, G. (2009). *Living Weapons.* Ithaca and London: Cornell University Press.
[95] Coll, S. (2005, August 7). Terrorists Turn to the Web as Base of Operations. Retrieved from Washingtonpost.com: http://www.washingtonpost.com/wp-dyn/content/article/2005/08/05/AR2005080501138.html.
[96] Koblentz, G. (2009). *Living Weapons.* Ithaca and London: Cornell University Press.
[97] Pita, R. (2009, April 30). Al Qaeda in the Islamic Maghreb (AQIM) and the Alleged Production of the Etiological Agent of Plague. Retrieved from ASA Newsletter: www.asanltr.com/newsletter/09-2/articles/092a.htm.
[98] Ibid.
[99] Ibid.

difficult to master. Analyses also concluded that the quality of the agent to be produced would be “crude,” that the outlines of the manufacturing were not accurate, and that the mass casualty potential of the agent would be "very low."[100] Intelligence reports suggest that al Qaeda attempts for the use of plague as a weapon have either failed or are in its infancy stages. However, those manuals have become part of other terrorist group attempts.

In 2014, a Syrian rebel group in northern Syria claimed to have taken a laptop from the Islamic State of Iraq and al-Sham (ISIS).[101] The laptop, owned by a Tunisian chemist and physicist, contained a 19-page document in Arabic on how to develop biological weapons and how to weaponize the bubonic plague from infected animals. The document also included instructions for how to test the weaponized disease.[102] The document advised to “use small grenades with the virus, and throw them in closed areas like metros, soccer stadiums, or entertainment centers and best to do it next to the air-conditioning.”[103] However, there was nothing on the computer that suggested that the jihadists already possessed the weapons.[104]

The BWC may deter nations from engaging biological weapons in state-sponsored warfare, but terrorists are not part of international treaties. In Jonathan Tucker’s “Motivations for and Against Proliferation: The case of the Middle East,” Tucker claims that there are many incentives and disincentives for acquiring biological

[100] Salama, S. (2005). Does Intent Equal Capability? Al-Qaeda and Weapons of Mass Destruction. *Nonproliferation Review, 12*(3).
[101] Doornbos, H. (2014, August 28). Found: The Islamic State's Terror Laptop of Doom. Retrieved from Foreignpolicy.com: http://foreignpolicy.com/2014/08/28/found-the-islamic-states-terror-laptop-of-doom.
[102] Ibid.
[103] Ibid.
[104] Ibid.

weapons. The most notable incentives include using bioweapons as 1) a deterrence and 2) as a force-multiplier against adversaries in the region.[105] In contrast, Tucker acknowledges that disincentives include 1) limited value with underlining security problems and 2) international norms against the use of a weapon that has been completely banned.[106] However, it had been shown that al Qaeda, ISIS, and potentially other international and domestic terror groups may consider the panic of biological weapon as an effective tool. As a result, US Homeland Security created scenarios as a guide to prepare for a possible *Y. pestis* attack as described below.

Plague terrorism scenarios

Today, plague is a dangerous pathogen classified both as a Select Agent by the US Health and Human Services, which identifies biological agents and toxins to have "the potential to pose a severe threat to both human and animal health"[107] *Y. pestis* is also classified as a Category A agent by the US CDC for its threat to national security.[108] From a global perspective, the World Health Organization estimated that if 50kg of *Y. pestis* were released as an aerosol over a city of 5 million people, 150,000 people would develop pneumonic plague and 36,000 of them would be expected to die. *Y. pestis* could remain viable in an aerosol form for 1 hour and disperse up to 10km. Furthermore, it would be expected that significant numbers of city inhabitants might attempt to flee the

[105] Tucker, J. (2000). Motivations for and Against Proliferation: The case of the Middle East. In R. Kilinskas, *Biological Warfare: Modern Offense and Defense.* Boulder, CO.
[106] Ibid.
[107] Centers for Disease Control and Prevention. (2014). *Federal Select Agent Program*. Retrieved from Select Agents and Toxins List: http://www.selectagents.gov/SelectAgentsandToxinsList.html.
[108] Centers for Disease Control and Prevention. (n.d.). *Bioterrorism Agents/Diseases*. Retrieved from Emergency Preparedness and Response: http://emergency.cdc.gov/agent/agentlist-category.asp.

area, which would further spread the disease.[109] Rapid diagnosis of pneumonic plague is crucial to limiting the risk of deaths. When antibiotic therapy is delayed more than 24 hours after the onset of symptoms, pneumonic plague is almost always fatal. There are indications that current terrorist groups are interested in *Y. pestis*, thus plague is perceived by the Homeland Security officials as a potential bioterrorism threat.

The US Department of Homeland Security is aware of possible attacks using weapons of mass destruction. The Federal interagency community developed "National Planning Scenarios" which contain fifteen all-hazards planning scenarios for use in national, federal, state, and local homeland security preparedness activities.[110] The scenarios represent multiple potential terrorist attacks and natural disasters. The document specifically outlines a potential pneumonic plague threat. The summaries of all the 15 scenarios including the expected fatalities, economic impact, and dispersal methods are outlined in Table 2.

[109] Inglesby, T. (2000, May 3). Plague as a Biological Weapon. Medical and Public Health Management. Journal of the American Medical Association, 2281-2290.
[110] US Department of Homeland Security. (March 2006). National Planning Scenarios. Washington DC: The Homeland Security Council. Retrieved from https://info.publicintelligence.net/DHS%20-%20National%20Planning%20Scenarios%20March%202006.pdf.

Table 2 Summary of 15 All Hazards Planning Scenarios

	Scenario	Fatalities	$ Loss	Dispersal Method
1	Nuclear: 10-Kiloton	Hundreds of Thousands	Hundreds of Billions	Device assembled on ground in a city
2	Biological: Anthrax	13,000	Billions	Aerosol from a truck through a city
3	Biological: Influenza	209,000-1.9 Million	$87-$203 Billion	Natural pandemic
4	**Biological: Plague**	**9,553**	**Millions**	**Release in bathrooms of major airports, sports arenas, and trains**
5	Chemical: Blister	150	$500 Million	Sprayed from light aircraft at a football stadium.
6	Chemical: Toxic Industrial	350	Billions	IED explosions using shipping crates
7	Chemical: Nerve	5,700	$300 Million	Sarin into ventilation systems of three large office buildings
8	Chemical: Chlorine	17,500	Millions	Explosion ruptures a storage tank
9	Major Earthquake	1,400	Hundreds of Billions	Natural disaster
10	Major Hurricane	1,000	Billions	Natural disaster
11	Radiological: Dispersal Devices	180	Billions	Detonated in three cities (subway contaminated)
12	Explosive: Improvised Explosive Devices	100	Millions	Detonated at a sports arena with public transportation concourses
13	Biological: Food Contamination	500	Millions	Contamination at a ground beef facility
14	Biological: Foot and Mouth	None (animal deaths)	Hundreds of Millions	Contamination of livestock posing as survey personnel
15	Cyber Attack	None	Hundreds of Millions	Attack of a financial infrastructure

Scenario #3 (outlined in yellow), a biological plague attack scenario, uses multi-phased approached that includes attacking the bathrooms of the city's major airport. The detailed scenario outlined in the planning guide is as follows:

"In Karachi, Pakistan, a member of the UA receives *Y. pestis* seed stock from Europe and South America via airmail and begins production. Once the *Y. pestis* production is complete, the UA operative departs for Beirut, Lebanon. After a brief stay in Beirut, she departs for a major U.S. airport, via Beirut, Lebanon, and Madrid, Spain, using commercial air. Upon arrival at the international airport, she is met by another UA operative and is escorted to a safe house. Three days later, a UA messenger arrives at the international airport from Karachi, Pakistan, via Madrid, Spain, and delivers 50% of the *Y. pestis* seed stock concealed in the battery compartment of a cellular telephone. Approximately three weeks later, another UA messenger arrives at the international airport from Karachi, Pakistan, via Athens, Greece, and delivers the remaining 50% of the *Y. pestis* seed stock concealed in the battery compartment of a second cellular telephone. After the arrival of the remaining *Y. pestis*, the UA agent begins full-scale production of the agent. Two months later, the UA orders agricultural sprayers. The UA also uses cash to purchase three used Sport Utility Vehicles (SUVs) from private citizens at three different locations for use in the attacks. They are stored in a warehouse until the agent is ready. Less than 1 month after the purchase of the SUVs, *Y. pestis* production is complete, and the UA begins weaponization of the biological agent. Once this process is finished, the UA operatives load the *Y. pestis* agent into the sprayers and prepare for deployment as planned. The following day, three UA members drive the three SUVs outfitted with Biological Warfare (BW) dissemination devices toward the city and execute their mission."[111]

[111] US Department of Homeland Security. (March 2006). National Planning Scenarios. Washington DC.

The three attacks were to target: 1) the bathrooms of the city's major airport, 2) the city's main sports arena, and 3) the city's major train station. After the attack, the scenario describes a total of 9,553 fatalities and 28,383 illnesses across 13 countries specifically the United States, Canada, Australia, Brazil, China, England, France, Germany, Japan, Kuwait, Mexico, Russia, and Saudi Arabia.[112] The scenario assumes sophisticated terrorists with capability and knowledge of using plague, dissemination efficiency across the three targets, the exposure rate of the victims, and the likelihood of transmitting the disease from person to person after infection. These worse-case scenarios establish a starting point for local and state officials to incorporate the science of infectious disease with the potential of a bioterrorist attack using an infectious biological agent.

The contagious nature of pneumonic plague makes it particularly concerning as a biological weapon.[113] Currently, plague is specifically listed as a Category A, bioterrorism agent or disease. It poses a risk to national security because it: 1) can be easily disseminated or transmitted from person to person, 2) results in high mortality rates and has the potential for major public health impact, 3) might cause public panic and social disruption, and 4) requires special action for public health preparedness.[114] That attention indicates that high populated areas need to be prepared for a possible plague

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The Homeland Security Council. Retrieved from https://info.publicintelligence.net/DHS%20-%20National%20Planning%20Scenarios%20March%202006.pdf.

[112] US Department of Homeland Security. (March 2006). National Planning Scenarios. Washington DC: The Homeland Security Council. Retrieved from https://info.publicintelligence.net/DHS%20-%20National%20Planning%20Scenarios%20March%202006.pdf.

[113] US Army Medical Research Institute of Infectious Diseases. (2011). Medical Management of Biological Casualties Handbook (7th ed.). Fort Detrick, MD.

[114] Centers for Disease Control and Prevention. (n.d.). *Bioterrorism Agents/Diseases*. Retrieved from Emergency Preparedness and Response: http://emergency.cdc.gov/agent/agentlist-category.asp.

attack and ensure any recommendations are based on scientific evidence. This scenario has been a foundation for multiple national and international exercises to test local, state, and country responses to a wide-spread plague outbreak or biological attack. Notable exercises using plague include Exercise Black ICE II in September 2009 between the United States and the Swiss government.[115] During that same time frame, the International Criminal Police Organization (INTERPOL) conducted a similar plague bioterrorism attack exercise in Warsaw, Poland involving the countries of Belarus, the Czech Republic, Finland, Poland, Slovakia, and the Ukraine as well as the WHO and the European Centre for Disease Control.[116] Both of these high-profile exercises indicate the need for preparedness for a plague attack with intelligence suggesting that terrorist groups have an interest in the plague pathogen. The aviation industry is particularly vulnerable and a probable target for bioterrorism.

Bioterrorism and aviation

American views on terrorism changed in 2001 when terrorists hijacked aircraft to use as suicide weapons against multiple targets. One month after the 9/11 attacks, biological warfare made a mark with the intentional mailings of Anthrax-filled letters. In the age of novel terrorist attacks, response to possible future attacks must be continually updated with new technology, new methods, and new policies. Aviation has proven to be a high value and high attention target for terrorists. Aviation security has possibly deterred terrorists from traditional bombing attacks, as evidenced by the decrease in

[115] Switzerland and the United States of America. (2010). *Black ICE II bioterrorism response international coordination exercise.* Geneva: Biological Weapons Convention.
[116] INTERPOL. (2009, November 9). *International Bioterrorism Tabletop Exercise*. Retrieved from INTERPOL: http://www.interpol.int/Public/BioTerrorism/tabletop/default.asp.

bombings and hijackings through the last several decades. This may leave aviation open to non-traditional attacks not commonly screened for such as biological weapons. These types of weapons are most effective in a dense population, as in an aircraft or in an airport. Terrorists may now be tempted to use the publicity of aircraft and aviation with the novelty of biological attacks. At present, there is no historical precedent for biological attacks in aviation. Aircrafts and airports have, in modern history, been high-value targets for terrorists. Biological attacks against airports and airplanes may be the next wave of the future.

Aviation as targets

Airline bombings and hijackings have declined from the 1970s. However, with the advent of 24-hour news networks and instant social media reports, recent airplane attacks and hijackings have become international news. Aviation gives terrorist groups a worldwide platform for their cause. In December 2016, a radical hijacked a Libyan plane using replica hand grenades, but after negotiations released all passengers and crew members.[117] Though there have been attempted airplane hijacking by terrorists such as in Libya, there have been no deaths due to terrorist hijackings since 9/11. Though airport security may be successful in decreasing terrorists' attempts at hijackings or other conventional attacks, aviation may now be open to non-traditional methods such as biological attacks.

However, the airports themselves may now be a more tempting target with many more individuals in a single location than one aircraft. Brian Jenkins, a leading expert in

[117] Dewan, A. (2016, Dec 24). *Malta hijackers surrender after releasing Libyan passengers.* Retrieved from CNN.com: http://www.cnn.com/2016/12/23/europe/malta-libya-plane-hijack/index.html.

aviation security, noted that "when faced with increased security, terrorists do not abandon commercial aviation as a venue for their violence. They attack airports instead…" He further commentated that "attacks on airports give terrorists the symbolic value they seek and guarantee the attention of the international news media."[118] Terrorist expert Bruce Hoffman notes that though far more people have died from car accidents, "there is considerably higher anxiety and fear about the possibility of being a victim of aviation terrorism than about automobile accidents."[119] Aviation terrorism is a personal threat to everyone. Most individuals (including their family and friends) have traveled by aircraft and potentially could become a target. The personalization and realization that the attack on an aircraft or in an airport "could have been me," raises the psychological level for any terrorist message.

As a recent example, on 28 June 2016, three suicide terrorists suspected to be part of ISIS, opened fired and detonated explosives strapped to their bodies in Istanbul's Ataturk Airport in Turkey.[120] In this attack, the individuals did not pass through security but stayed in the open area of arrivals, departures, and in the parking lot claiming a total of 44 lives and injuring over 240 individuals.[121] The attacks were similar to the Brussels, Belgium airport attack that happened only two months before in April 2016. In that attack, ISIS terrorist detonated two bombs in the check-in area of the airport while

[118] Jenkins, B. (2011, January 25). *Why Terrorists Attack Airports*. Retrieved from CNN Opinion: http://www.cnn.com/2011/OPINION/01/25/jenkins.moscow.bombing/index.html?section=cnn_latest.
[119] Forest, J. (2008). Chapter 8: Modern Terrorist Threats to Aviation Security. In Andrew Thomas, *Aviation Security Management.* Westport, CT: Praeger Security International.
[120] Karimi, F. (2016, June 30). *ISIS leadership involved in Istanbul attack planning, Turkish source says.* Retrieved from CNN.com: http://www.cnn.com/2016/06/30/europe/turkey-istanbul-ataturk-airport-attack/index.html.
[121] British Broadcasting Corporation. (2016, June 30). *Istanbul airport attackers 'Russian, Uzbek and Kyrgyz'.* Retrieved from Europe News: http://www.bbc.com/news/world-europe-36670576.

another bomber detonated another bomb at a nearby Metro station; the attack killed 32 individuals and wounded over 340.[122] In both attacks, none of the terrorists needed to pass through security check-points and were able to cause significant death, destruction, and panic in a well-traveled area. Since it is conceivable that an airport would encompass many travelers representing multiple nations, it provides the terrorists a worldwide statement. Airports are a tempting target for any terrorist that may want to use biological weapons in the future.

Aviation security

Though airports and aviation may be a target for biological weapons, the industry is not prepared for such an attack. The agency directly responsible for the security of airports and airlines is the Transportation Security Administration (TSA) in the US Department of Homeland Security. In the modern era of aviation, the reaction in aviation security has been in direct response and proportional to the most recent threat. In 2001, TSA implemented the removal of shoes in response to a failed al Qaeda airplane attack using explosives that an operative smuggled in his shoes.[123] TSA has since implemented shoe removal before screening into the passenger waiting area.[124] In 2006, TSA implemented the "3-1-1 Liquid Rule for Carry-on Baggage."[125] This was in direct response to an arrest of 8 men, who were part of a British Terror Cell, for conspiring to

[122] British Broadcasting Corporation. (2016, June 30). *Istanbul airport attackers 'Russian, Uzbek and Kyrgyz'*. Retrieved from Europe News: http://www.bbc.com/news/world-europe-36670576
[123] Thomas, C. (2002, September 1). Courage in the Air. Retrieved from http://www.time.com/time/covers/1101020909/aattendants.html.
[124] US Department of Homeland Security. *How to Get Through the Line Faster*. Retrieved from Transportation Security Administration: http://www.tsa.gov/travelers/airtravel/screening_experience.shtm.
[125] US Department of Homeland Security. *Make Your Trip Better Using 3-1-1*. Retrieved from Transportation Security Administration: http://www.tsa.gov/311/index.shtm.

blow up seven transatlantic flights using liquid explosives.[126] In 2010, TSA deployed body scanners and explosive trace detection after a Nigerian man working for al Qaeda was arrested for conspiring to kill 300 people aboard a Northwest flight bound for Detroit, Michigan with explosive powder taped to this leg.[127] Since then, TSA expanded the random use of Explosive Trace Detection technology to screen passenger's hands and carry-on luggage.[128] Currently, Advanced Imaging Technology (AIT) has been widely deployed to detect possible threats on the body of an individual.[129]

Despite the increases in security measures, it has been noted that at the turn of the 21st century, terrorists have had a better than 50-percent success rate in getting bombs on board aircraft.[130] Security measures are forcing terrorists to design more concealed explosive devices that use smaller quantities of explosives and less reliable detonating mechanisms.[131] In 2010, one year after the failed attempt to detonate the explosive power on the Northwest passenger airplane, the same suspected bomb-maker plotted to circumvent security by targeting cargo. In this plan, a Hewlett-Packard printer and a motherboard contained explosives were planted on a cargo plane destined from Yemen to

[126] US Department of Homeland Security. *UK 2006 Liquid Explosive Plot Trial Overview*. Retrieved from Transportation Security Administration: http://www.tsa.gov/press/happenings/terror_plot_hearing.shtm.
[127] Caulfield, P. (2001, March 24). Christmas 2009 'underwear bomber' targeted Detroit because it was the cheapest flight. *NY Daily News.com.*
[128] US Department of Homeland Security. (2010, February 17). *TSA Expands Use of Explosive Trace Detection Technology at Airports Nationwide*. Retrieved from Transportation Security Administration: http://www.tsa.gov/press/releases/2010/0217.shtm.
[129] US Department of Homeland Security. (n.d.). Advanced Imaging Technology (AIT). Retrieved from Transportation Security Administration: http://www.tsa.gov/approach/tech/ait/index.shtm.
[130] Jenkins, B. (2010). *The Tenth Year: A Briefing on Terrorism Issues to New Members of the 112th Congress.* Santa Monica, CA: RAND Corporation.
[131] Ibid.

synagogues in Chicago, Illinois.[132] Since a printer normally has wires, the standard screening did not detect anything unusual.[133] The oversight prompted officials to increase all cargo security and screening measures.[134]

The increase in security measures at checkpoints may be steering terrorists away from passenger checkpoints, as was seen in the Istanbul and Brussel airport attacks, or towards cargo targets, as was seen in the Yemen attempt. This improvement in passenger security acts a deterrent. Martonosi in his study concluded that "deterrence might appreciably magnify the benefits of even modest gains in the chance of thwarting a terrorist at the security checkpoint."[135] Jacobson further concluded that "the expected number of successful attacks decreases as the level of deterrence increases…and the lower number of expected successful attacks results from additional threats being detected in previously unscreened baggage."[136] However, as better screening measures have deterred terrorists from gaining access to secure areas and moved toward open areas, security fails to foreshadow and screen for the next terrorist type of event. Officials seem to wait for the next attack to implement new and different screening measures. There may come a point where the risk-benefit of smuggling explosives now steer terrorists toward innovative and less screened for methods of terror, namely biological release. These new methods of attack may be in powder or aerosolized form. They may

[132] CNN Wire Staff. (2010, Nov 01). *Airports tighten security after bomb plot.* Retrieved from CNN.com: http://www.cnn.com/2010/US/11/01/yemen.security.concern.
[133] Ibid.
[134] Ibid.
[135] Martonosi, S. (2006). How Effective Is Security Screening of Airline Passengers? *Interfaces, 36*(6), 545-552.
[136] Jacobson, S. (2005). Assessing the impact of deterrence on aviation checked baggage screening strategies. *International Journal of Risk Assessment and Management, 5*(1), 2-15.

also use a suicide terrorist as a vector. Security, currently, is reactionary and not forward thinking in preparation. Security measures may stop conventional attempts, but allow for more innovative methods at the hands of the terrorists. Though terrorists may try to use plague for a biological attack based on historical exploration, and though US Homeland Security has created scenarios to deliberate about responses to plague attacks, it is important to ensure that the current science of the pathogen is appropriately factored into the communication and public health interventions.

Plague: airport or aircraft bioterrorism scenarios

Terrorists, in an effort to maximize terror, may need to determine non-conventional means for their attack to stand out amongst the current wars and random criminal acts. Using *Y. pestis* in an attack may cause the perception of another "Black Death" in a high public area such as an airport. There is a captive audience. However, as will be described in this dissertation, deaths will be limited to only those exposed, and widespread person to person disease transmission is not expected. Historically terrorist may be considering the plague agent but the success rate is likely to be poor, and would only serve to cause panic. However, that may be the ultimate intention.

The focus of the antiterrorist efforts of the US air transportation system to date has been on the detection of concealed arms or explosives; essentially no capability exists to detect biological warfare agents effectively and affordably. However, the success of a biological attack depends on how effectively the perpetrator could disseminate it and how many people would get exposed and infected. It is conceivable that a bioterrorist may use aerosolized *Y. pestis* for a biological attack at an airport. It is hypothesized that the

terrorist would not risk detection at the security screenings to go the flight departure areas. An aerosol attack would have just as much impact at the common areas before the security lines. In the ticketing area, many more passengers traveling to many different locations could be affected and thus cause more panic. Anyone who was at the airport at the time of the attack could be a potential victim. An aerosol attack could be disguised within an explosion or apart from an explosion. Individuals at the airport would flee the scene, and it may take several hours or days for emergency personnel to determine if *Y. pestis* was released. Discovery of the pathogen would lead to hundreds or thousands of worried individuals wondering if they have the plague. Any cough would be construed as the start of a sickness and the hospitals would be overwhelmed with individuals who were near the airport or at the airport at some point in the past 3 days. However, realistically, though the threat of plague is possible, it is highly probably that any explosion would kill *Y. pestis* and the possibility of infection would be minimal.

If a terrorist was able to improve the technology and create a clandestine attack, the location and size of the aerosol spray would determine the number of potential victims. However, if the aerosol device was not detected but detected based on symptoms, it may take a few days to determine the common denominator of the victims. A slow acting agent such as *Y. pestis* may expose thousands while responders would have a difficult time determining who visited the airport. If the attack occurred before the airport screening area, the attack would affect not only ticketed passengers, but family, friends, and business personnel that were visiting the airport. Within days, the panic crowds may have traveled globally without responders knowing exactly who was

exposed. At this point, a well-designed plan and communication announcement become extremely important. However, a successful attack using *Y. pestis* that caused deaths would be limited to exposed individuals who become infected and death is expected within 3 days. An attack will not cause a wide-spread outbreak as will be shown in the results.

If the terrorists are completely deterred from an aerosolized attack at an airport, they may use themselves as a vector. However, this type of attack is not expected to be successful as pneumonic plague has a very low person-to-person transmission rate and a fast incubation rate. It would not be an efficient use of one individual and would only serve to panic a population that may have shared an aircraft with the individual. However, whether there was an aerosol attack or suicide terrorist attack using pneumonic plague or another pathogen of concern, certain preventative measures may be taken to ensure efficient responses that will be described in the conclusion. These responses that include a combination of infection control measures and communication measures will not only mitigate any possible biological attacks but also aid in minimizing the spread of natural outbreaks of diseases.

Psychology in public health crises

The psychology of certain disease may also dictate the strategy of the communication. It has been shown that for bioterrorism or pandemic events, given the dread and uncertainty surrounding them, the likelihood is high that people will respond

emotionally. [137] It may be required to alleviate fears instead of just presenting facts. A condition known as "health anxiety" is defined as an inappropriate or excessive preoccupation and concerns about one's health status relative to his or her actual state of health.[138] It has been shown that there is a spike in health anxiety referrals during times of mass media coverage of serious diseases, outbreak, or bioterror event.[139] The public may remain fearful of a disease that they are not commonly exposed to, even though they may intellectually realize how unreasonable the fear may be.[140] In fact, people or groups may revert to more basic or instinctive fight-or-flight responses and improperly exaggerate reactions to communications.[141]

This psychology may present roadblocks to effective communication. The fear and stress may not allow individuals to respond to normal types of communication. One theory known as "mental noise theory" states that when people are stressed, they are attending to a great deal of internal mental noise and are less able to properly react or process the information provided.[142] However, other studies suggest that public fear may present valuable windows for intervening in habit formation.[143] If the public feels empowered to take action that will reduce their risk of harm, it may reduce the

[137] Glik, D. (2007). Risk Communication for Public Health Emergencies. The Annual Review of Public Health(28), 33-54.
[138] Blakey, S. (2015). Tracing "Fearbola": Psychological Predictors of Anxious Responding to the Threat of Ebola. Cognitive Therapy and Research, 39, 816-825.
[139] Ibid.
[140] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication
[141] Ibid.
[142] Glik, D. (2007). Risk Communication for Public Health Emergencies. The Annual Review of Public Health(28), 33-54.
[143] Rosell, A. (2014). Regulating Fear: The Case of Ebola in the United States. University of Illinois College of Law Legal Studies Research Paper No. 15-05.

psychological impact of a crisis.[144] Thus with proper communication, instead of dismissing a fear, it may become an opportunity to enhance good public health practices. For example, once it was proven that the risk of Ebola exposure and infection to the general public was small, it may be an opportunity to remind the public the importance and benefit of simple behaviors such as hand washing and getting a flu shot, in order not to confuse Ebola with the symptoms of influenza.[145]

Understanding the public's perception of a disease and the risk factors involved will guide the type of information and education presented. However, several simple concepts with previous lessons learned will help prepare for the next outbreak of concern especially when the disease may or may not be disseminated by airline travel. The public needs to be educated early and empowered with preventative measure techniques. This will reduce panic, increase preventative measure compliance, and ultimately diminish the spread of disease.

Panic in this content is described as "a sudden overpowering fright" or "a sudden unreasoning terror often accompanied by mass flight" as described in Webster's dictionary.[146] It is in this laymen's view of panic that this research focuses the attention for future behavioral changes. However, in the clinical definition of the ICD-10 Classification of Mental and Behavioral Disorders, F41.0 Panic disorder [episodic paroxysmal anxiety] is defined as "recurrent panic attacks, that are not consistently associated with a specific situation or object, and often occurring spontaneously (i.e. the

[144] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication.
[145] Blakey, S. (2015). Tracing "Fearbola": Psychological Predictors of Anxious Responding to the Threat of Ebola. Cognitive Therapy and Research, 39, 816-825.
[146] Merriam-Webster. (2017). Panic. Retrieved from Dictionary: https://www.merriam-webster.com/dictionary/panic

episodes are unpredictable). The panic attacks are not associated with marked exertion or with exposure to dangerous or life-threatening situations."[147] In a clinical setting, a person does not have a clinical diagnosis of panic with a perceived exposure to a dangerous situation. An outbreak may cause individuals to panic in an acute sense but would be outside the scope of a clinical definition. Thus, panic in this context is not viewed as a mental disorder.

Surat, India: the case of pneumonic plague panic

With the threat of plague still viable across the world, it is conceivable that an outbreak may occur in an area that will cause widespread panic and evacuations. Individuals that flee may use airlines as transportation and unintentionally spread the disease. This was the outcome of a September 1994 plague threat in Surat, India. Usually, India has minor outbreaks during the spring or autumn, but then dies out during summer due to the weather conditions.[148] The cause of the plague in Surat can be traced back to an earthquake in the nearby Beed district that disrupted the territorial equilibrium between wild rats and house rats aggravated by a flood in the Tapti River.[149] During this time, an urban growth caused an increased in slums and unhygienic conditions within Surat. [150] These events all fueled the plague epidemic in September 1994 triggered by a series of environmental and zoonotic events.

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[147] World Health Organization. (1993). *The ICD-10 Classification of Mental and Behavioural Disorders, Diagnostic criteria for research.* Geneva: United Nations.
[148] Roul, A. (2003). Plague Outbreaks in India: Surat and Himachal Pradesh. In P. Chari (Ed.), *Biological Weapons Issues and Threats* (pp. 115-137). New Delhi: India Research Press.
[149] Ibid.
[150] Ibid.

In the first week of September 1994, a bubonic plague outbreak occurred in the Mamla village in the Beed district due to a sudden increase in rat and flea densities. The first reported victim in Surat happened on 19 September when a man was declared dead on arrival at the Surat Civil Hospital with another eight people from the slums soon dying from similar symptoms of high fever, cough and blood in the sputum.[151] Diagnosis of pneumonic plague was confirmed on 25 September when *Yersinia pestis* was grown from specimens in 18 patients. Newspapers chronicled 460 plague cases between September 20 and September 25, and over 1,061 more suspected.[152]

When the public learned about the suspected plague, one-fourth of Surat's population (0.7 million) fled the city.[153] The people who fled took all types of transport including taxis, tempos (three wheelers), trains and buses and paid whatever necessary causing transport operators to make a tremendous profit.[154] Migrant workers from the textile mills and jewelry industries tried to leave the city to get back to their home towns and villages.[155] Unfortunately, this only facilitated the spread of disease. Surat does not have an airport, thus no plague was exported to other countries and no plague was imported into the United States. [156]

The local and international news coverage aggravated the panic that spread throughout Surat. There were news reports that reminded the public of the "Black Death"

[151] Roul, A. (2003). Plague Outbreaks in India: Surat and Himachal Pradesh. In P. Chari (Ed.), *Biological Weapons Issues and Threats* (pp. 115-137). New Delhi: India Research Press.
[152] Dutt, A. (2006). Surat Plague of 1994 Re-examined. *Southeast Asian Journal of Tropical Medicine and Public Health*, *37*(4), 755-760.
[153] Ibid.
[154] Dutt, A. (2006). Surat Plague of 1994 Re-examined. *Southeast Asian Journal of Tropical Medicine and Public Health*, *37*(4), 755-760.
[155] Ibid.
[156] Deodhar, N. (1998). Plague that Never Was: A Review of the Alleged Plague Outbreaks in India in 1994. Journal of Public Health Policy, 19(2), 184-199.

and other plague occurrences from the past.[157] Prominent media outlets described the plague and scene in Surat as "reaching biblical proportions," as a "medieval scourge," or a "medieval horror show."[158] Tourists canceled their flights to India and airplanes out of India were suspect.[159]

The World Health Organization and CDC tried to take measures to control the situation. By 5 October, approximately one month later, the plague epidemic was over.[160] It is unknown exactly what factors caused the epidemic to die out in only a few short weeks, but suspected it could have been from natural causes or control measures, including the widespread prophylactic use of antibiotics.[161] Within three days of the identification of the disease, 95% of those remaining in Surat were taking the antibiotic tetracycline.[162] In the end, 47 people died of the plague.[163] Though the plague was not as wide-spread as first reported, economically the plague panic left a devastating mark. By the time the suspected plague outbreak was contained, the tourist and trade industry had been affected and India lost over $2 Billion USD in the next 3 months of the year.[164]

The case of Surat emphasizes the need for strong scientific evidence and the need for good communication when a suspected case of pneumonic plague occurs. A

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[157] Dutt, A. (2006). Surat Plague of 1994 Re-examined. *Southeast Asian Journal of Tropical Medicine and Public Health, 37*(4), 755-760.
[158]Dutt, A. (2006). Surat Plague of 1994 Re-examined. *Southeast Asian Journal of Tropical Medicine and Public Health, 37*(4), 755-760.
[159] Ibid.
[160] Ibid.
[161] Barnes, K. (2014). Social vulnerability and pneumonic plague: revisiting the 1994 outbreak in Surat, India. Environmental Hazards, 13(2), 161-180.
[162] Dahlburg, J. (1994, Oct 26). India Plague Epidemic Called 'Limited Outbreak'. Retrieved from Los Angeles times: http://articles.latimes.com/1994-10-26/news/mn-54932_1_india-plague-epidemic.
[163] Roul, A. (2003). Plague Outbreaks in India: Surat and Himachal Pradesh. In P. Chari (Ed.), *Biological Weapons Issues and Threats* (pp. 115-137). New Delhi: India Research Press.
[164] Cash, R. (2000). Impediments to global surveillance of infectious disease: consequences of open reporting in a global economy. Bulletin of the World Health Organization, 78(11), 1358-1367.

pneumonic plague outbreak, whether a natural occurrence or by a potential bioterrorist attack may begin indistinguishable from one another. However, the public health response that follows and the cooperation needed by governments and international organizations remain identical. It is important to know the impact of travelers and the impact of public health policies when there is an outbreak of pneumonic plague.

The following chapters outline the efficacy of different public health measures including travel restrictions, entry and exit procedures, quarantine and isolation, and communication. The public health measures are outlined in the historical context of past infectious diseases particularly SARS, H1N1, and Ebola to determine their effectiveness. If a case similar to Surat should occur with a potential imported case of pneumonic plague into the New York City, this dissertation will outline the recommendations needed to ensure that the outbreak and panic are contained based on scientific evidence and epidemiological modeling.

CHAPTER 2: PUBLIC HEALTH IN AVIATION

The world is connected by airline travel with billions of passengers a year and growing. This research will outline the current literature on aircraft as a vector for a potential disease outbreak and the impact of interventional public policies. The literature has some research on airline travel disseminating a disease using individuals as vectors versus the risk of in-flight transmissions. A review of past incidents, specifically SARS, H1N1, and Ebola, will evaluate how international travel policies may have affected the spread of infectious disease outbreaks. The literature has some analytical data derived from theoretical models on the impacts of restricting airline travel due to a disease outbreak, including the impact of targeted entry and exit procedures. This research will analyze current interventional policies, including travel restrictions, entry and exit procedures, quarantine and isolation, and risk communication and their impact in the containment of disease outbreaks. Lessons learned must be established and future programs must be prepared in the event of another infectious disease epidemic.

Risk factors in the spread of disease

Researchers have examined two possible roles for airplanes in global outbreaks: the role of airplanes as incubators and the role of airplanes as vectors. Two schools of thought emerge from those who believe that the aircraft ventilation system limits diffusion of disease pathogens during a flight and those that believe that the aircraft itself

could serve as a transmitter of highly infectious diseases. This dissertation will do a scientific literature review of past incidences of in-flight transmission and determine the role of the physical aircraft as an enabler of disease spread or if the aircraft serves more as a vector by shuttling individuals with disease from one area to another. Recommendations will be provided on the most effective methods of disease spread control that may be either with the aircraft itself or with travel policies.

Airplanes as incubators

During a normal airplane flight, individuals will sit in an enclosed environment known as the cabin. The several environmental variables within the cabin may be manipulated by the flight deck for the comfort of the passengers that include temperature and pressurization. The cabin ventilation in the aircraft includes re-circulated air from the engines mixed with the outside air. Figure 7 shows a typical air circulation pattern with air entering the cabin from overhead, circulating across the aircraft, and exiting near the bottom of the aircraft.[165]

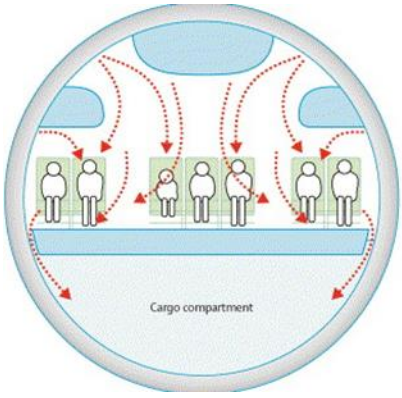

Figure 7 Air Circulation Pattern in a Typical Aircraft

[165] Mangili, A. (2005, March 12). Transmission of infectious diseases during commercial air travel. *The Lancet, 365*, 989-996.

This pattern will limit the air across the aisles of the aircraft instead of having air migrating from the front of the aircraft to the back.[166] Furthermore, most aircraft maintain a policy of introducing "fresh air at a rate of 50%, which is mixed with recirculated air and filtered through high-efficiency particulate air (HEPA) filters, with a 99.9% efficiency rate of removal of airborne biological contaminants...the entire cabin air volume is exchanged every 2 to 3 minutes."[167] During an experiment of disease dispersal through a normal aircraft air circulating system, JP Rydock concluded that "infectious diseases are transmitted primarily between people sitting in close proximity to each other in an aircraft cabin and that partial recirculation of ventilation air in the cabin has a negligible impact on occupant's risk of exposure."[168] These effects limit the transmission of infectious diseases to only "close contact" passengers, which the WHO defines as the same row plus 2 rows ahead and 2 rows behind.[169]

Some studies show that the HEPA systems in aircraft are a protective factor against disease transmission. Even though there is a perception that travel in a confined aircraft cabin creates an increased risk of person-to-person disease transmission, no studies show an increase in health risks as compared to other modes of transportation.[170] There is evidence on how protective air circulation could be in an aircraft. In one particular incident, an aircraft had an inoperative air conditioning system and was

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[166] Mangili, A. (2005, March 12). Transmission of infectious diseases during commercial air travel. *The Lancet, 365,* 989-996.
[167]Ong, R. (2009). Airline Policies and Procedures to Minimize the Spread of Disease. *Research on the Transmission of Disease in Airports and on Aircraft.* Washington DC: Transportation Research Board.
[168] Rydock, J. (2004). Tracer Study of Proximity and Recirculation Effects on Exposure Risk in an Airliner Cabin. *Aviation, Space, and Environmental Medicine, 75*, 168-171.
[169] Gaber, W. (2009). Screening for Infectious Diseases at International Airports: The Frankfurt Model. *Aviation, Space, and Environmental Medicine, 80,* 595-600.
[170] Mangili, A. (2005, March 12). Transmission of infectious diseases during commercial air travel. *The Lancet, 365,* 989-996.

delayed on the ground for 3 hours. This seemed to be the index case where 72% of all the travelers on the flight became infected by a single passenger suffering from influenza.[171] With the 3-hour delay and the air circulation off, it is hypothesized that the influenza dispersed at a more natural rate in a confined space. The particles of disease were not scrubbed through filters, and thus the passengers were more at risk for infection. Through this study and various case experimentations, the results indicate that disease transmission in a functioning aircraft is less likely than in other locations or environments.

However, depending on the aircraft type, there might be various patterns of the re-circulated air. Using the normal pattern of air circulation and definition of close contact, it might be shown that in a Canadair CRJ 100, a total of 20 patients would be classified as close contact and in an Airbus A319-100 or a Boeing B747, it could be as many as 50 contacts.[172] Furthermore, the close contact definition does not apply to aircraft carriers that allow for open seating, or if a traveler decides to move seats. In these cases, it may be difficult to determine the exact location of an infectious index case.

However, it has been shown that transmission on the aircraft is possible. There were four documented airline flights with in-flight transmissions during the 2003 SARS outbreak.[173] Many of these cases occurred within the WHO definition of close contact, but also several cases occurred outside of it. It may be that the WHO definition of close contact is too strict and should be expanded. In the case of an in-flight transmission of

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[171] Gaber, W. (2009). Screening for Infectious Diseases at International Airports: The Frankfurt Model. *Aviation, Space, and Environmental Medicine, 80,* 595-600.
[172] Ibid.
[173] Ibid.

SARS from Hong Kong to Beijing, only 31 percent of persons who fit the definition of close contact became ill, as compared with the 11 percent of persons who were seated elsewhere on the plane, and yet contracted SARS.[174] However, the aircraft as an incubator is a very low risk of disease transmission especially in fully functional aircraft in flight.

Airplanes as vectors

As stated above, literature reviews show a low risk of in-flight disease transmissions. However, individuals that travel may be exposed to a disease at an outbreak location, and if infected, may become an unwilling vector. During the 2003 SARS pandemic, studies concluded that the main mode of introduction of SARS to countries was via airline travelers.[175] In 2009, studies also showed that there was a strong correlation between international air-traffic patterns and risk of H1N1 disease importation.[176] Figure 8 visually describes the spread of SARS across the Earth through air travel pathways.[177] Figure 9 visually depicts the spread of H1N1 through air travel.[178]

[174] Gaber, W. (2009). Screening for Infectious Diseases at International Airports: The Frankfurt Model. *Aviation, Space, and Environmental Medicine, 80*, 595-600.
[175] Wilder-Smith, A. (2003). Short Communication: Low Risk of Transmission of Severe Acute Respiratory Syndrome on Airplanes: The Singapore Experience. *Tropical Medicine and International Health, 8*, 1035-1037.
[176] Khan, K. (2009). Spread of a Novel Influenza A (H1N1) Virus via Global Airline Transportation. *The New England Journal of Medicine, 361*, 212-214.
[177] Colizza, V. (2007). Epidemic Pathways. Retrieved from Competition On Visualizing Network Dynamics: http://vw.indiana.edu/07netsci/entries/submissionspg2.html.
[178] GLEAMviz. (2009, September 23). *The Global Epidemic and Mobility Model*. Retrieved from Column on Airneth: http://www.gleamviz.org/2009/09.

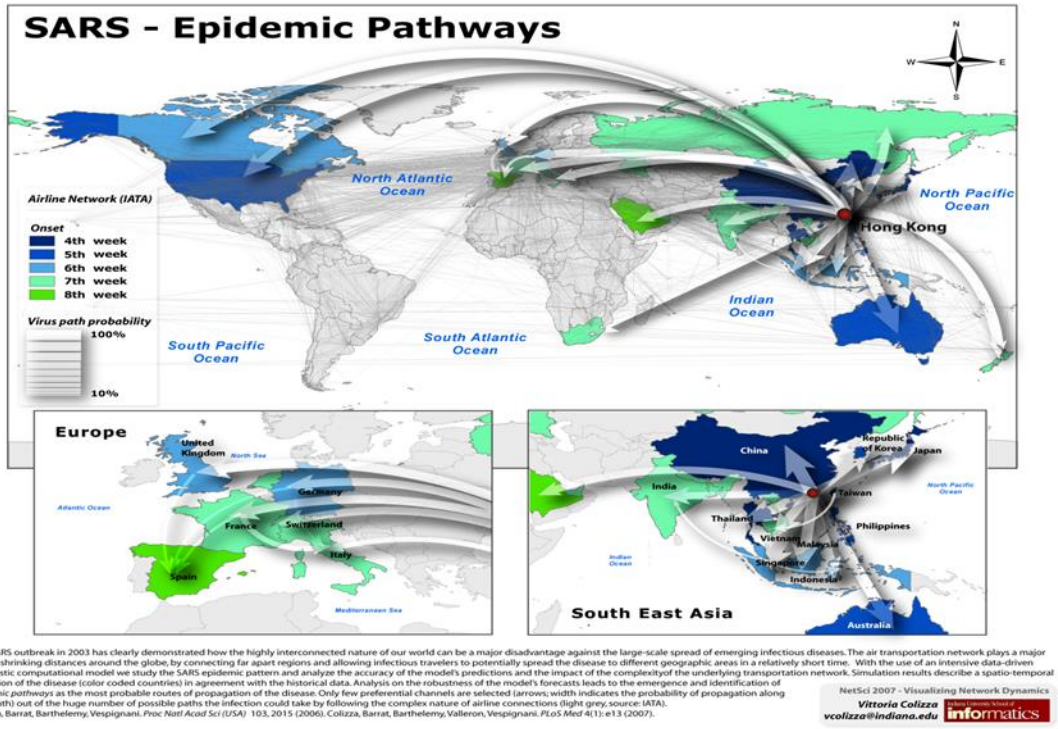

Figure 8 Spread of SARS Across Air Travel Pathways

Figure 9 Spread of H1N1 Across Air Travel Pathways

Air travel has been implicated in the rapid spread of disease in the modern world. In one particular study that analyzed 30 years of data on seasonal influenza, Lessler concluded that the "spread of epidemics at the interstate level may only need to take air transportation into account.''[179] Another study also analyzed 9 years of US influenza data and found that domestic air travel volume predicted the rate of influenza spread, and international air travel affected the timing of influenza mortality.[180] In essence, the authors found that in general, influenza was found to spread more slowly when the number of domestic air travelers was lower, and the peak of the influenza season was found to come later when the number of international air travelers was lower, particularly in the month of September.[181] Furthermore, that same study also provided evidence on the influence of air travel immediately following the United States 9/11 World Trade Center terrorist attacks. A 10% drop in aircraft following the attacks delayed the flu season by approximately 2 weeks.[182]

Ebola also spread from the confines of West Africa to the United States and Europe through air travel. Figure 10 depicts the relative risk of Ebola importation to various countries using air travel.[183] The countries of the United States and the United Kingdom confirmed importation from patients from West Africa who traveled by air. However, due to the disease characteristics of Ebola and the medical interventions

[179] Lessler, J. (2009, February). The Cost of Simplifying Air Travel When Modeling Disease Spread. PLoS ONE, 4(2), e4403.
[180] Brownstein, J. (2006, October). Empirical Evidence for the Effect of Airline Travel on Inter-Regional Influenza Spread in the United States. PLoS Medicine, 3(10), 1826-1835.
[181] Ibid.
[182] Ibid.
[183] McGinty, J. (2014, October 17). *Using Air Traffic Data to Predict Ebola's Spread*. Retrieved from The Wall Street Journal: http://blogs.wsj.com/numbers/using-air-traffic-data-to-predict-ebolas-spread-1837.

against Ebola, these individuals did not cause wide-spread endemics in either the US or UK. Ebola is not spread through the air, thus there were no reported in-flight transmissions of Ebola. The imported cases of Ebola were strictly as a vector.

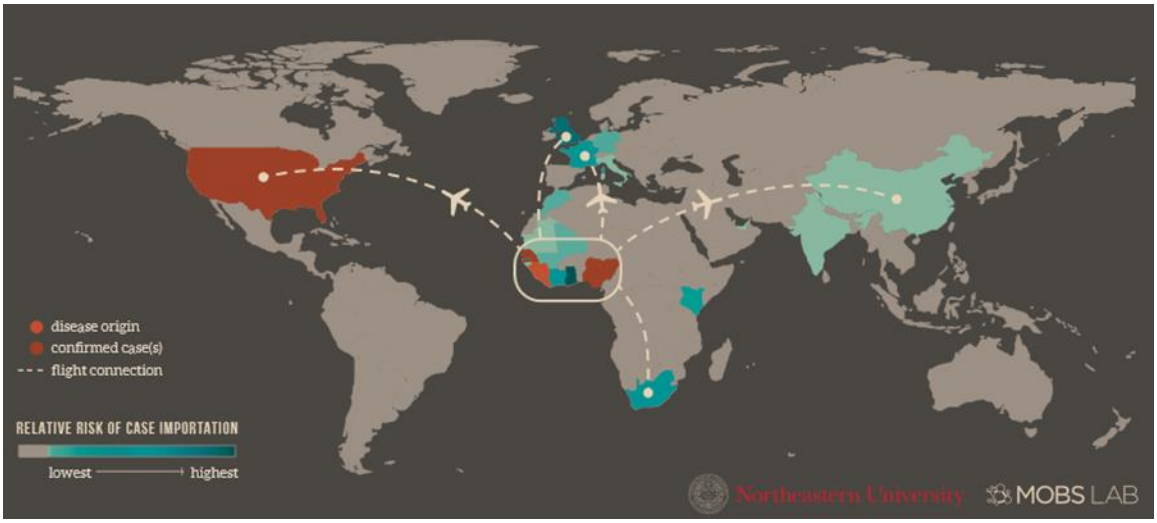

Figure 10 Risk of Ebola Across Air Travel Pathways

Airline travel may subject individuals to the spread of disease in a confined space. These infected passengers may now become unwilling vectors to their final destination. However, as noted, the spread of disease is very low in the aircraft. Though there were cases of in-flight transmission of SARS and influenza, the overall threat is minimal. There were no cases of in-flight transmission of Ebola, but that disease does not transmit through the air. The next level of protection would be reasonable sets of guidelines for countries and passengers to abide by to decrease and limit the importation of diseased travelers that may have boarded the aircraft already infected.

Public health interventions and responses

For infectious disease outbreaks characterized by high person-to-person transmission and high death rate in a short period of time, it is imperative to have policies in place for appropriate airline travel, quarantine and isolation, as well as educational communication to limit public fear and panic. As seen in the previous examples, the world and the United States have been unprepared to deal with suspected and actual outbreaks, resulting in billions of dollars spent and unnecessary anxiety and despair. Appropriate contingency plans for either natural or intentional outbreaks are necessary for the protection of the economy as well as the physiological and psychological welfare of the population.

This research will describe the current public health policies that have been implemented during past disease outbreaks. This research will analyze the effectiveness of 4 specific policies that directly impact the airline traveler. These include: 1) travel restrictions, 2) entry and exit procedures, 3) quarantine and isolation, and 4) education and communication. Each method will be thoroughly outlined. Based on past lessons learned, this project will determine the foundational recommendations in the event of a pneumonic plague outbreak.

Efficacy of travel restrictions

In most cases, mathematical models indicate that travel restrictions have a limited effect on the spread of a disease, unless almost all travel is restricted very soon after the epidemic is detected.[184] GS Cooper developed stochastic models of the spread of

[184] Cooper, B. (2006, May). Delaying the International Spread of Pandemic Influenza. *Public Library of Science Medicine.*

influenza to determine the effectiveness of state-based travel restrictions. According to Cooper's models, "if 99.9% of all travel could be stopped, epidemics in most cities would be delayed by no more than 4 months."[185] However, others studies indicate that "a 50% travel reduction produces a delay equal to the doubling time of the number of cases."[186] For example, if the disease were doubling cases every month, then a 50% reduction in travel would delay the introduction of the disease by a month to the area that introduced the travel restriction. However, if the disease is progressing very rapidly and doubling cases every week, then a travel restriction would only delay the disease introduction by one week. A travel restriction would be most effective for slow moving disease or at the beginning of an epidemic.

There is a risk of infected individuals traveling and spreading a disease. To mitigate that, the Aerospace Medical Association issued guidelines for air travel.[187] However, these guidelines are not binding by any international law. Patients and physicians are under no obligation to abide by the recommendations which state that "individuals with any contagious disease that could be transmitted to other passengers should postpone air travel."[188] Despite the recommendations, in the event of a panic, passengers may not seek medical attention, and in turn medical professionals may not necessarily contact the airline. Even if the physician knew the passenger had an infectious

[185] Cooper, B. (2006, May). Delaying the International Spread of Pandemic Influenza. Public Library of Science Medicine.
[186] Poletto, M. (2014, October 23). Assessing the impact of travel restrictions on international spread of the 2014 West African Ebola epidemic. Retrieved from Rapid Communications: http://www.eurosurveillance.org/images/dynamic/EE/V19N42/art20936.pdf.
[187] Aerospace Medicine Association Medical Guidelines Task Force. (2003, May). *Aerospace Medical Association.* Retrieved from Medical Guidelines for Airline Travel; 2nd Edition: http://www.asma.org/publications/medicalguideline.php.
[188] Ibid.

disease, they may not know about any future travel plans. Also, there is no incentive for the patient to disclose any such information. It is evident that travel restrictions that fall on the responsibilities of the patient may be ineffective and not readily abided by. However, it is likely that those too ill would not travel thereby reducing the risks of in-flight transmission and disease exportation.

The World Health Organization has very specific guidelines on travel restrictions. However, these guidelines rely on national compliance with an emphasis on recommendations for passengers. It usually falls on the International Civil Aviation Organization (ICAO) to support the WHO in the implementation of health measures in aviation. The H1N1 outbreak of 2009 did test the World Health Organization and their most recent implementation of policy based on the lessons learned from the outbreak of SARS. ICAO changed some provisions in 2007, to include states to have a pandemic preparation plan for aviation, and cabin crew advice on how to identify a suspected case of an in-flight illness.[189] However, during the 2009 H1N1 outbreak, the World Health Organization decided not to impose any travel restrictions with the realization that any restrictions would have very little effect on the spread of H1N1 especially since it was confirmed in many parts of the world.[190] In addition, travel restrictions were not advised as the illness was mild in most cases and treated by Tamiflu.[191] In the cases of SARS and H1N1, the WHO could not contain either. In the case of Ebola, WHO recommended that

[189] Evans, A. (2009, May). *International Civil Aviation Organization.* Retrieved from Presentation on Influenza A (H1N1) and the Aviation Sector: http://www.icao.int/icao/en/med/guidelines.htm.
[190] World Health Organization. (2009, May 1). *World Health Organization.* Retrieved from WHO / No rationale for travel restrictions: http://www.who.int/csr/disease/swineflu/guidance/public_health/travel_advice/en/index.html.
[191] Evans, A. (2009, May). *International Civil Aviation Organization.* Retrieved from Presentation on Influenza A (H1N1) and the Aviation Sector: http://www.icao.int/icao/en/med/guidelines.htm.

there should be no general ban on international travel or trade.[192] It might be shown that if the world is not cooperative, it may be wiser to limit resources nationally without impacting international markets and income.

Efficacy of entry and exit procedures

Air travel restrictions may be a plausible reaction to an epidemic; however, short of closing down airports and grounding airlines, they might not have any effect on the containment of infectious diseases. In the cases of SARS, H1N1, and Ebola, the WHO did not implement travel restrictions, but focused on airport entry and exit procedures. It has been noted that even though exit screening is favored by the WHO over entry procedures, some governments believe that facilities need to be put in place for entry screening in their own country because public health authorities cannot control the efficacy of exit screening undertaken outside their own borders.[193] It is a basic premise of the International Health Regulations (IHR) to have basic exit and entry procedures in place at major international airports. Annex 1 of the IHR, Core Capacity Requirements for Designated Airports, Ports and Ground Crossings, include the capacities "to apply entry or exit controls for arriving or departing travelers and to provide assessment and if required quarantine of suspect travelers."[194]

The procedures for entry and exit passenger restrictions are reliant on symptoms. A passenger may be able to "fake" through the entry or exit in early disease stages. It has

[192] World Health Organization. (2014, October 23). Statement on the 3rd meeting of the IHR Emergency Committee regarding the 2014 Ebola outbreak in West Africa. Retrieved from Media Center: http://www.who.int/mediacentre/news/statements/2014/ebola-3rd-ihr-meeting/en/#.
[193] Evans, A. (2009). Prevention of Spread of Communicable Disease by Air Travel. *Aviation, Space, and Environmental Medicine, 80*, 601-602.
[194] World Health Organization. (2008). *International Health Regulations; Second Edition.*

been noted that airport entry screening would be unlikely to detect more than 10% of passengers latently infected with an infectious disease when boarding an aircraft.[195] A 2014 technical report on the entry and exit screening measures for Ebola, also indicated that even the best temperature screening scheme will miss up to 20% of the fever symptoms, will miss those travelers concealing their fever especially if taking anti-fever medications, as well as miss two-thirds of infected cases as the disease is still incubating and not yet presenting symptoms.[196] Those who are experiencing severe symptoms may be too ill to travel. Well-publicized entry and exit procedures may also have a deterrent value, where an individual may not be willing to risk losing airfare if the traveler feels they may be confined at the airport for a suspected illness. The entry and exit procedures would have to be refined enough to find those who are not obviously sick. Previous cases have shown that it would be difficult to achieve proper disease containment during a possible outbreak through entry and exit procedures, and are subject to procedural failures.

The use of entry and exit screening for infectious diseases has not been proven in the three disease example of SARS, H1N1, or Ebola to be effective or efficient in controlling the spread of disease. As an example, Canada did not identify any SARS cases even though they screened 6.5 million individuals and invested over C$7.5 million for airport entry screening measures.[197] The index case was a Canadian woman who

[195] Cooper, B. (2006, May). Delaying the International Spread of Pandemic Influenza. *Public Library of Science Medicine.*
[196] European Centre for Disease Prevention and Control. (2014). Infection prevention and control measures for Ebola virus disease Entry and exit screening measures. Stockholm.
[197] European Centre for Disease Prevention and Control. (2014). Infection prevention and control measures for Ebola virus disease Entry and exit screening measures. Stockholm.

returned to Toronto, Canada from Hong Kong before SARS was recognized, and only 4 other cases of Canadian SARS were classified as imported.[198] None of the 5 imported Canadian cases were recognized by screening measures. As an example of exit procedures, the CDC invested resources to screen individuals departing the countries of Guinea, Liberia, and Sierra Leone. Of the 36,000 airline passengers screened with temperature screening, 77 were denied boarding a flight; however, none of those 77 tested positive for Ebola after subsequent follow-up testing.[199] In the US, of all the passengers screened, not a single case of Ebola was identified. The fourth case of Ebola identified in the US was a Doctors without Borders physician that self-identified his increased oral temperature nine days after returning to New York from Guinea. No secondary cases of Ebola were detected in New York after monitoring individuals he came into contact with.[200]

Though the entry and exit procedures have not proven to be able to identify disease cases in the past, the CDC does claim that effective exit and entry procedures provide important outcomes including: 1) deterring travel by ill persons, 2) reducing the likelihood of a traveler becoming ill during travel, 3) allowing the quick identification of any illness in screened individuals, 4) limiting contact of persons being evaluated with other persons, 5) facilitating rapid and appropriate clinical care for ill travelers, and 6) providing the arriving traveler with public health education and links with public health

[198] Abraham, T. (2005). Twenty-First Century Plague. Baltimore: The Johns Hopkins University Press.
[199] European Centre for Disease Prevention and Control. (2014). Infection prevention and control measures for Ebola virus disease Entry and exit screening measures. Stockholm.
[200] Centers for Disease Control and Prevention. (2015, April 3). Ebola Virus in a Humanitarian Aid Worker - New York City, October 2014. Morbidity and Mortality Weekly Report.

authorities.[201] Thus, entry and exit procedures may instill confidence in government actions thus reducing or delaying the risk for disease spread.

Efficacy of quarantine and isolation

Quarantine and isolation are some of the oldest methods of controlling communicable disease outbreaks. Its history is traceable to 14th century public health practices requiring ships arriving in Venice from plague-infected ports to sit at anchor for 40 days before disembarking.[202] Though there are provisions in place for quarantines and isolations, employment of those laws may be ineffective, unethical, and possibly counterproductive. As defined by the Centers for Disease Control and Prevention (CDC), isolation "is used to separate ill persons who have a communicable disease from those who are healthy", while quarantine "is used to separate and restrict the movement of well persons who may have been exposed to a communicable disease to see if they become ill."[203] In aviation, the IHR has quarantine guidelines in place. Conversely, the International Civil Aviation Organization (ICAO) in its "Guidelines for States concerning the Management of Communicable Disease Posing a Serious Health Risk" note that "quarantine of large numbers of travelers is not likely to be justified and may be difficult to implement. After, the acute phase, it is also not likely to significantly prevent the

[201] Centers for Disease Control and Prevention. (2014). *Airport Exit and Entry Screening for Ebola.* Morbidity and Mortality Weekly Report (MMWR). Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6349a5.htm.
[202] Cetron, M. (2005). Public Health and Ethical Considerations in Planning for Quarantine. Yale Journal of Biology and Medicine, 78, 325-330.
[203] Centers for Disease Control and Prevention. (2009, March). Legal Authorities for Isolation and Quarantine. Retrieved from CDC: Quarantine and Migration Health: http://www.cdc.gov/quarantine/AboutLawsRegulationsQuarantineIsolation.html.

spread of a major disease outbreak."[204] It is evident that international organizations do not restrict the use of quarantines in an emergency; however, the regulations also mention the limitation of quarantine effectiveness. Quarantines may also have unintentional consequences costing countries significant amount of funds without any real benefits. Some research indicates that "screening and quarantining entering travelers at international borders has not substantially delayed virus introduction in past pandemics, except in some island countries, and will likely be even less effective in the modern era."[205]

A case of an ineffective quarantine order came in May of 2007, when a US citizen diagnosed with extensively drug-resistant tuberculosis was given a CDC order not to travel. This person ignored the order and traveled to Italy and Canada before re-entering the United States.[206] Though Customs and Border Protection was notified, he was not stopped at the border. The customs agent explained that he was not a doctor, thought the infected man seemed perfectly healthy and took the issued warning as merely discretionary.[207] The patient later voluntarily went to a New York hospital where he was isolated.[208] This case shows that though the United States has a legal provision in place

[204] International Civil Aviation Organization. (2010). Aviation Medicine Section (MED). Retrieved September 2010, from Guidelines for States Concerning the Management of Communicable Diseases Posing a Serious Public Health Risk: http://www.icao.int/icao/en/med/guidelines.htm.
[205] Infanti, J. (2013). A literature review on effective risk communication for the prevention and control of communicable diseases in Europe. Stockholm: European Centre for Disease Prevention and Control
[206] Markel, H. G. (2007). Extensively Drug-Resistant Tuberculosis: An Isolation Order, Public Health Powers, and a Global Crisis. *Journal of the American Medical Association, 298* (1), p. 83-86.
[207] Conroy, S. (2007, May 31). Inspector Ignored Warning on TB patient. *CBSNEWS Health Watch*, http://www.cbsnews.com/stories/2007/05/31/health/main2869316.shtml.
[208] Swendiman, K. (June 5, 2007). *Extensively Drug-Resistant Tuberculosis (XDR-TB): Quarantine and Isolation.* American Law Division. Congressional Research Service.

for isolation and quarantine, success is not guaranteed and is subject to procedural failures.

Quarantines may also prove to have substantial costs to countries, states, and local governments. The US enacted several quarantine measures for individuals returning from Ebola-stricken areas. In one particular case of a family of six returning from West Africa serving house quarantine in West Haven, Connecticut; it was estimated that the city spent approximately $1000 a day to enforce the quarantine.[209] This would top over $21,000 for a full 21-day Ebola quarantine per family or individual required to abide by a quarantine order.

Efficacy of communication

Communication is an essential part of an emergency response in the event of a disaster. In 2004, the Director-General of the World Health Organization, Dr. Jong-wook Lee stated, "we have had success in the [last] five years in controlling outbreaks, but we have only recently come to understand that communications are as critical to outbreak control as laboratory analyses or epidemiology."[210] Effective communication can ensure the proper dissemination of proper health information, which will enhance the likelihood that populations at risk will take preventative measures, reassure populations that are not at risk and calm those who are, and facilitate relief efforts. Proper communication results in reduced morbidity and mortality due to the public taking proper action and minimizing

[209] West, M. (2014, Oct 29). The High Cost of Quarantine. Retrieved from The Wall Street Journal: http://www.wsj.com/articles/the-high-cost-of-quarantine-and-who-pays-for-it-1414546114
[210] World Health Organization. (2005). Effective Media Communications during Public Health Emergencies. Geneva.

panic. In contrast, dissemination of poor or incorrect information may lead to panic, loss of life, and may have a negative impact on the economy.

The impact of poor communication was realized by the Chinese during their first encounter with SARS. In a WHO conference on "Outbreak Communication," Chinese officials recognized that the government should have been forthright in publicly acknowledging that a new flu was extremely deadly and contagious. This prevented neighboring countries from possibly minimizing imported cases and notifying world health care workers that may have come into contact with the new disease.[211] However, once communication started studies showed that the impact was critical in containing the disease. In one particular study in China, the time lag between symptom onset and hospitalization decreased significantly from 5 to 6 days to 2 days in which the public were made aware of symptoms and were able to personally take action.[212] After-action reports acknowledged that in Vietnam, who immediately openly reported cases, was able to be one of the first countries to stop a local transmission of SARS.[213]

However, the impact of communication is extremely important when dealing with an outbreak that is more "frightening" to the public, if not more deadly. This was seen with the recent outbreak of Ebola where communication was extremely challenging across multi-cultures especially in African and Western nations. The science of behavior in relation to the science of the disease spread became extremely important to contain the

[211] World Health Organization. (2004). Outbreak Communication. Singapore: Communicable Disease Surveillance and Response.
[212] Pang, X. (2003). Evaluation of Control Measures Implemented in the Severe Acute Respiratory Syndrome Outbreak in Beijing, 2003. The Journal of the American Medical Association, 290(24), 3215-3221.
[213] World Health Organization. (2004). Outbreak Communication. Singapore: Communicable Disease Surveillance and Response.

disease both in the US and in West Africa. In order to contain Ebola, studies showed that it took more than 20% of the response devoted to rumor management and translating technical information into a locally appropriate language.[214]

Communication errors could create panic especially when the public expects immediate and accurate information. However, the processing of that information may be dependent on sociocultural backgrounds, risk perspectives, and life circumstances.[215] Habits and long-held practices may be exaggerated and individuals may just follow the bad examples set by others in their immediate community.[216] Even though having a diversity of messengers from government agencies and communities is likely to improve the quality of communication, studies have shown that it may be insufficient unless the actual content of messages is compatible with the values of the community.[217]

Communicating effectively with the public about specific threats is the key to successful emergency management and public health. Emphasis has been on the importance of population trust in the source of information and on the medium through which the information is delivered.[218] Studies have shown that stopping a disease

[214] World Health Organization. (2004). Outbreak Communication. Singapore: Communicable Disease Surveillance and Response.
[215] Vaughan, E. (2012). Predicting Response to Reassurances and Uncertainties in Bioterrorism Communications for Urban Populations in New York and California. Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science, 10(2), 188-202.
[216] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication.
[217] Vaughan, E. (2012). Predicting Response to Reassurances and Uncertainties in Bioterrorism Communications for Urban Populations in New York and California. Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science, 10(2), 188-202.
[218] Savoia, E. (2013). Communications in Public Health Emergency Preparedness: A Systematic Review of the Literature. Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science, 11(3), 170-184.

outbreak require that public health professionals and government leaders gain the community's confidence through constant and relevant information flow.[219]

Overall, many studies have shown the difficulty in effective risk communications to the public during a crisis. It is noted that failures of communication that include the release of inaccurate, confusing, or contradictory information have the potential to increase levels of fear, panic, and suspicions that may ultimately inhibit efforts to halt the spread of disease.[220] Studies have shown that under intense stress, individuals may lose the details of health and safety messages because they are juggling multiple facts during a crisis, not remembering as much of the information, and misinterpreting confusion action messages.[221] It is the intention of this dissertation to research lessons learned and best practices on the best educational methods that will reduce the risk of disease spread.

[219] Glass, T. (2002, January 15). Bioterrorism and the People: How to Vaccinate a City against Panic. Clinical Infectious Diseases, 34, 217-223
[220] Ibid.
[221] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication.

CHAPTER 3: CASE STUDIES: SARS, H1N1, AND EBOLA

The world and the United States have been caught unprepared to deal with suspected and actual outbreaks that have cost billions of dollars and caused unnecessary anxiety and despair. This research will review past incidences and uncover the roles that the commercial airline industry and public policy have in the spread of diseases. This research will provide a historical outline and scientific review of 3 past disease outbreaks where air travel played a significant role. The diseases of note include the 2003 Severe Acute Respiratory Syndrome (SARS) that spanned 37 countries, the 2009 Influenza H1N1 which affected over 200 million individuals worldwide, and the 2014 Ebola which spread to multiple countries through air travel. An analysis of lessons learned will be conducted from articles in the published literature, as well as from published news releases from the World Health Organization (WHO), the International Civil Aviation Organization (ICAO), the Centers for Disease Control and Prevention (CDC), as well as other organizations involved during the time of the crises.

2003 Severe Acute Respiratory Syndrome (SARS)

A new atypical pneumonia, which originated in the Guangdong province of China in late 2002, quickly spread to Hong Kong, Taiwan, Singapore, Canada, Vietnam, and, ultimately, to a total of 37 countries; it was named the Severe Acute Respiratory Syndrome (SARS). Overall, the World Health Organization (WHO) reported 8,096

probable cases of SARS in less than 1 year; 27 of those cases were in the United States.[222] Shortly after SARS first emerged, the disease was identified as a novel coronavirus called SARS–CoV, which was determined to be genetically distinct from previously known human and animal coronaviruses. Characterization of the virus indicated that it was a single-stranded, positive-sense RNA virus. SARS–CoV was discovered to be primarily transmitted by close contact from person to person via large respiratory droplets. Initial signs of illness included flu-like symptoms with fever, cough, body aches, and malaise after an incubation period ranging from 1 to 14 days and end with most patients developing pneumonia. Epidemiological investigations showed that SARS disproportionately affected health care workers and close contacts of SARS patients, such as family members. Higher mortality was observed in older patients, with more than 50 percent of fatalities occurring in people 65 years of age or older. Children were the least likely to develop the disease.

For the SARS pandemic, the WHO and ICAO first issued travel alerts and restrictions to limit the aircraft as a disease vector and incubator. However, 150 cases were suspected before the WHO put out their first travel advisory. In March 2003, the WHO issued a global alert about cases of a severe atypical pneumonia in Hong Kong, Hanoi, Singapore, and Toronto.[223] In April 2003, WHO specifically received reports on 9 persons, with a history of travel to Hong Kong dating from 15 March 2003, who

[222] Cassels, F. (2012). Severe Acute Respiratory Syndrome. The Jordan Report.
[223] Wilder-Smith, A. (2006). The severe acute respiratory syndrome: Impact on travel and tourism. Travel Medicine and Infectious Disease, 4, 53-60.

subsequently developed SARS and imported the disease to Taiwan, China, and Singapore.[224]

In only a couple of days, the WHO issued travel advisories as evidence mounted that this unusual pneumonia was spreading by air travel along international routes; approximately 500 cases of SARS were reported in 12 different countries.[225] There were four documented airline flights with in-flight transmissions of SARS during the 2003 outbreak.[226] In one particular case, when precautions were not in place for SARS, a stewardess on a Singapore flight had served and cleaned the tray of a SARS passenger.[227] The passenger was a doctor who had treated the first admitted case of SARS in Singapore.[228] This is a case in which close contact was truly evident and transmission did occur. In another flight from Hong Kong to Beijing, researchers determined that 22 passengers may have become ill from one SARS infected individual on the aircraft, 9 of which were sitting outside the WHO definition of "close contact."[229] In the case of the flight from Hong Kong to Beijing, 31 percent of persons who fit the definition of close contact became ill, as compared with the 11 percent of persons who were seated

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[224] World Health Organization. (2003, April 2). Global Alert and Response (GAR). Retrieved from Update 19 - China deepens its collaboration to contain SARS, WHO revises its advice to international travellers as new data come in: http://www.who.int/csr/sars/archive/2003_02_02b/en.
[225] World Health Organization. (2003, March 25). Global Alert and Response (GAR). Retrieved from Update 9 - Updated travel advice: http://www.who.int/csr/sars/archive/2003_03_25/en.
[226] Gaber, W. (2009). Screening for Infectious Diseases at International Airports: The Frankfurt Model. *Aviation, Space, and Environmental Medicine, 80*, 595-600.
[227] Wilder-Smith, A. (2003). In-flight transmission of Severe Acute Respiratory Syndrome (SARS): A Case Report. *Journal of Travel Medicine, 10*, 299-300.
[228] Wilder-Smith, A. (2003). Short Communication: Low Risk of Transmission of Severe Acute Respiratory Syndrome on Airplanes: The Singapore Experience. *Tropical Medicine and International Health, 8*, 1035-1037.
[229] Olsen, S. (2003). Transmission of the Severe Acute Respiratory Syndrome on Aircraft. *The New England Journal of Medicine, 349* (25), 2416-2422.

elsewhere on the plane, and yet contracted SARS.[230] Figure 11 shows the depiction of the passengers seated the Hong Kong to Beijing flight who contracted SARS and their seated arrangements in relation to the index case who was seated in 14E.[231] The definition of close contact would have been only applied to passengers in Row 12, 13, 14, 15, and 16.

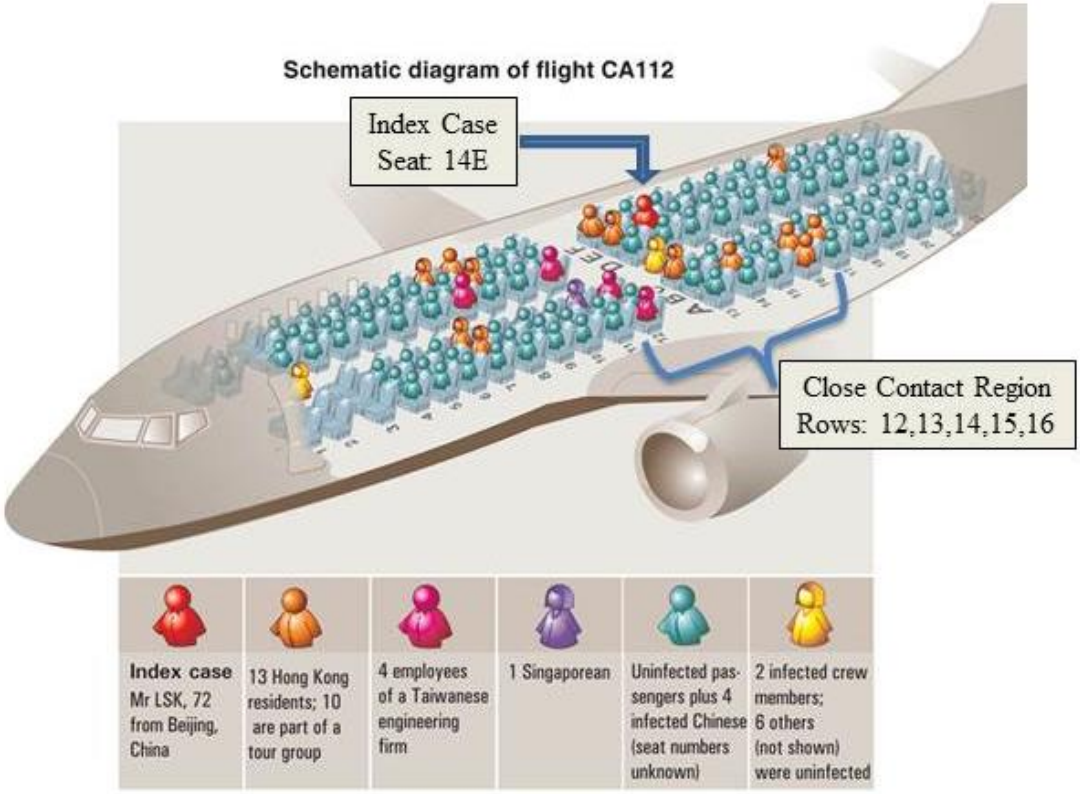

Figure 11 In-Flight Transmission of SARS in a Flight from Hong Kong to Beijing

[230] Olsen, S. (2003). Transmission of the Severe Acute Respiratory Syndrome on Aircraft. *The New England Journal of Medicine*, *349* (25), 2416-2422.
[231] China CDC. (2006, May 19). WHO. Retrieved from SARS How a Global Epidemic was Stopped: http://www.yncdc.cn/newsview.aspx?id=19185.

In May 2003, the number of SARS reported cases rose to over 6900 in 29 countries on five continents.[232] The disease dispersal added further evidence that it appeared to be primarily spreading along the routes of international air travel.[233] However, WHO did not recommend travel restrictions but instituted travel recommendations and alerts.[234] Saudi Arabia was one of few countries that banned the entry of people who had visited or resided in China, Hong Kong, Taiwan, Singapore, Vietnam, or Canada.[235] However, for that particular time period, it coincided with Hajj, a pilgrimage that attracts more than 2 million Muslims from all over the world.[236] No cases of SARS were ever reported in Saudi Arabia.[237] No other worldwide travel bans were instituted.

Singapore established specific entry point measures to prevent the further importation of SARS after the travel alerts. However, large outbreaks of SARS had already been reported before appropriate measures had been put in place. Annelies Wilder-Smith et al instituted a retrospective study to describe the incidence and impact of SARS in Singapore when national entry point screenings were implemented.[238] The

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[232] World Health Organization. (2003, May 8). Global Alert and Response (GAR). Retrieved from Update 50 - WHO extends its SARS-related travel advice to Tianjin, Inner Mongolia and Taipei in China: http://www.who.int/csr/sars/archive/2003_05_08/en.

[233] World Health Organization. (2003, July 1). Update 92 – Chronology of travel recommendations, areas with local transmission. Retrieved from Emergencies preparedness, response: http://www.who.int/csr/don/2003_07_01/en.

[234] World Health Organization. (2003, March 15). World Health Organization issues emergency travel advisory. Retrieved from Emergencies preparedness, response: http://www.who.int/csr/sars/archive/2003_03_15/en.

[235] Wilder-Smith, A. (2006). The severe acute respiratory syndrome: Impact on travel and tourism. Travel Medicine and Infectious Disease, 4, 53-60.

[236] Ibid.

[237] Ahmed, Q. (2006). Health Risks at the Hajj. *Lancet, 367*, 1008-1015.

[238] Wilder-Smith, A. (2003). Experience of Severe Acute Respiratory Syndrome in Singapore: Importation of Cases, and Defense Strategies at the Airport. Journal of Travel Medicine, 10, 259-262.

Singapore measures included the following: 1) issuing Health Alert Notices to air passengers arriving from affected areas, 2) visual screening for all passengers arriving from SARS-affected areas, and 3) temperature screening and thermal scanners which replaced the visual screening.[239] Passengers who appeared to be unwell or had a temperature of >37.5 degrees Celsius were sent by special ambulance to a local hospital for further screening. Thermal scanners were not only implemented in the airport but on airport road points to check the temperature of all departing and arriving passengers. After implementation of all measures, Singapore did not report any further importation of patients with SARS. In the 442,973 air passengers screened, 136 were sent to the hospital, but none were diagnosed as having SARS.[240] In fact, the cases of SARS could only be traced back to six individuals who entered the country before entry policies were in place. Only one of those individuals transmitted it to other individuals in the country and was the single cause of the Singapore SARS outbreak. The author does point out that the large number of measures were at a considerable cost and inconvenience with no actual SARS case identified.[241]

A combined retrospective study found that in Canada, China (including the mainland and Hong Kong), and Singapore, no cases of SARS were detected by thermal scanning among the greater than 35 million international travelers scanned at entry in their airports during the SARS epidemic.[242] Exit procedures for the SARS pandemic also

[239] Wilder-Smith, A. (2003). Experience of Severe Acute Respiratory Syndrome in Singapore: Importation of Cases, and Defense Strategies at the Airport. *Journal of Travel Medicine, 10*, 259-262.
[240] Ibid.
[241] Ibid.
[242] Wilder-Smith, A. (2006). The severe acute respiratory syndrome: Impact on travel and tourism. Travel Medicine and Infectious Disease, 4, 53-60.

yielded similar results to the entry procedures. Combined data from China, Canada, and Singapore indicate that no cases of SARS were detected among the greater than 7 million people who underwent thermal scanning at the exit.[243]

Large-scale quarantine strategies were implemented during the 2003 SARS outbreak in several different countries. Overall, strategies associated with timely and successful control of local outbreaks were characterized by rapid and aggressive use of community containment strategies. Some countries that instituted quarantines that were flexible and voluntary found that it may have been a factor in the successful containment of SARS.[244] In Canada, over 15,000 persons with an epidemiologic exposure to SARS were instructed to remain in voluntary quarantine for 10 days between February and June of 2003.[245] At the end of the epidemic, Canada suffered 438 cases, of which 224 occurred in Toronto; 44 resulted in death.[246] Gupta, in his study on SARS in Toronto, estimated that the quarantine policies implemented in Canada may have averted over 13,000 infections, assuming those ill continued to infect their close contacts at an unimpeded rate.[247] In Taiwan, over 150,000 persons were quarantined, 24 of who were found to have SARS.[248] Hsieh, in his study, noted that the quarantine in Taiwan was helpful in identifying people with SARS more quickly, and concluded that their isolation prevented

[243] Wilder-Smith, A. (2006). The severe acute respiratory syndrome: Impact on travel and tourism. Travel Medicine and Infectious Disease, 4, 53-60.
[244] US Department of Health and Human Services. (2006). HHS Pandemic Influenza Plan, Appendix 4. Principles of Modern Quarantine. Washington.
[245] Hawryluck, L. (2004). SARS Control and Psychological Effects of Quarantine, Toronto, Canada. Emerging Infectious Diseases, 10(7), 1206-1212.
[246] Gupta, A. (2005). The economic impact of quarantine: SARS in Toronto as a case study. Journal of Infection, 50, 386-393.
[247] Ibid.
[248] Hsieh, Y. (2005). Quarantine for SARS, Taiwan. Emerging Infectious Diseases, 11(2), 278-282.

secondary infections.[249] The United States did not implement any quarantine measures during SARS.

The travel alerts did produce the effect of reducing tourism travel in the East Asia area by 41%.[250] By July 2003, the last two areas in the world – Toronto and Taiwan – which experienced local transmission of SARS, broke the chain of person to person transmission, thus the WHO declared that "this achievement will mean that the SARS coronavirus is no longer thought to be circulating in the human population."[251]

The CDC used the Internet as the primary means of communication during the SARS epidemic. The number of visitors that visited the CDC's travelers' health website (www.cdc.gov/travel) averaged 3.6 million in 2002; this same website had over 4 million visits by mid-year of 2003 during SARS.[252] Furthermore, approximately one-third of the visits were from outside of the United States with Taipei, Taiwan originating more visits than any city in the United States.[253] The CDC's Division of Global Migration and Quarantine (DGMQ) generated over 125 documents on the SARS pages of the CDC website and included updates and alerts in 7 different languages; over 1.5 million visits were made to those documents from all over the world.[254] Also, quarantine officers in the United States handed out over 2.7 million Health Alert Notices to passengers disembarking from nearly 12,000 flights from areas with SARS.

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[249] Hsieh, Y. (2005). Quarantine for SARS, Taiwan. Emerging Infectious Diseases, 11(2), 278-282.
[250] Wilder-Smith, A. (2006). The severe acute respiratory syndrome: Impact on travel and tourism. Travel Medicine and Infectious Disease, 4, 53-60.
[251] World Health Organization. (2003, July 1). Update 92 – Chronology of travel recommendations, areas with local transmission. Retrieved from Emergencies preparedness, response: http://www.who.int/csr/don/2003_07_01/en.
[252] Arguin, P. (2004). Health Communication during SARS. Emerging Infectious Diseases, 10(2), 377-380.
[253] Ibid.
[254] Ibid.

The impact of communications may have had a significant role in the control of SARS in China. One study noted that there was a decrease in the time between illness onset and hospitalization due to the improvements in communication among health care workers, public health personnel, and the general public as the outbreak progressed.[255] China first announced the outbreak in a press conference on April 20, 2003, and staged a multifaceted communication campaign that included 13 more press conferences, billboards, bus advertisements, 24-hour SARS hotline, seminars, daily 2-hour educational programs, distribution of over 8 million pamphlets and compact disk, and traditional red neighborhood banners that educated and motivated the public to protect themselves and fight together to control SARS.[256] The impact is suggested by the observation that the time lag between symptom onset and hospitalization decreased significantly during the outbreak from a median of 5 to 6 days before the outbreak was made public to 2 days afterward.[257]

Singapore was widely praised for its handling of the SARS epidemic in 2003. The country received international accolades for its decisive leadership at an early stage, the transparency and honesty of its communication messages, and earning the trust and confidence of Singaporeans with both symbolic and substantive measures to reassure the populace.[258] Singapore observed its first SARS case on March 6, 2003 when three

[255] Pang, X. (2003). Evaluation of Control Measures Implemented in the Severe Acute Respiratory Syndrome Outbreak in Beijing, 2003. The Journal of the American Medical Association, 290(24), 3215-3221.
[256] Ibid.
[257] Ibid.
[258] Infanti, J. (2013). A literature review on effective risk communication for the prevention and control of communicable diseases in Europe. Stockholm: European Centre for Disease Prevention and Control.

persons who had traveled to Hong Kong were admitted to hospitals for pneumonia.[259] By April, a total of 201 probable cases of SARS and 722 suspect cases were reported.[260] However, in swift action, Singapore amended their laws and prohibited possible infectious persons from going to public places and from breaking home quarantine. In addition, persons throughout the country had been requested to monitor body temperature and seek medical care if any signs of SARS appeared.[261] The strict approach proved effective, as Singapore had no further transmission of SARS infection within hospital wards or from imported cases.[262]

With lessons learned from the SARS pandemic, the International Civil Aviation Organization (ICAO) instituted recommendations for states to have a pandemic preparation plan for aviation, and cabin crew advice on how to identify a suspected case of an in-flight illness.[263] The speed of scientific understanding and information exchange, combined with critical public health measures such as patient isolation and infection control, eventually led to successful outbreak containment. In July 2003, the World Health Organization officially declared the outbreak over. There have been no new SARS cases reported since April 2004.[264]

In summary, the SARS experience demonstrated that a disease with a high transmission rate may travel too fast for travel alerts and travel restrictions to have any

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[259] Centers for Disease Control and Prevention. (2003, May 9). Severe Acute Respiratory Syndrome --- Singapore, 2003. Retrieved from Morbidity and Mortality Weekly Report: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5218a1.htm.
[260] Ibid.
[261] Ibid.
[262] Ibid.
[263] Evans, A. (2009, May). *International Civil Aviation Organization.* Retrieved from Presentation on Influenza A (H1N1) and the Aviation Sector: http://www.icao.int/icao/en/med/guidelines.htm.
[264] Cassels, F. (2012). *Severe Acute Respiratory Syndrome.* The Jordan Report.

effect, and that instituting any restrictions after the importation of the disease into a country would have minimal effect on the spread of disease. It also showed that the WHO definition of close contact may need to be expanded as transmission of a disease may occur outside the 2 rows on an aircraft. SARS also exposed the ineffectiveness of entry and exit thermal procedures and the costs of implementing such a measure without any impact on the spread of disease or significant identification of diseased individuals. However, the after-action reports did determine that communication may have been very effective at containing the disease with voluntary quarantines and personal infectious prevention measures that individuals could implement to minimize person to person spread. Studies found that countries such as Vietnam and Singapore, with a robust communication plan, were able to mitigate the disease spread faster than China who delayed communication to their public. Some of these lessons learned with implemented 6 years later with the outbreak of H1N1.

2009 Influenza H1N1

The 2009 H1N1 influenza outbreak was a new strain first detected in the United States in April 2009. This virus was spreading from person to person worldwide. On June 11, 2009, the World Health Organization (WHO) declared that a pandemic of 2009 H1N1 flu was underway.[265] In the United States, influenza surveillance systems routinely used to monitor seasonal influenza activity were successfully used to track and characterize the 2009 influenza A (H1N1) pandemic, showing patterns of influenza activity that differed dramatically from those of seasonal influenza. The influenza activity during April–

[265] Centers for Disease Control and Prevention. (2010, February). H1N1 Flu. Retrieved from 2009 H1N1 Flu ("Swine Flu") and You: http://www.cdc.gov/h1n1flu/qa.htm.

November 2009 was at higher than expected levels for that time of year. The spread of the 2009 H1N1 occurred similarly to other influenza viruses; mainly from person to person through coughing, sneezing or talking. The symptoms of H1N1 flu virus in people included fever, cough, sore throat, runny or stuffy nose, body aches, headache, chills and fatigue. CDC laboratory studies showed that no children and very few adults younger than 60 years old had existing antibody to the H1N1 flu virus; however, about one-third of adults older than 60 may had antibodies against this virus.[266] Each year, in the United States, on average 36,000 people die from flu-related complications and more than 200,000 people are hospitalized from flu-related causes; more than 90% of deaths and about 60 percent of hospitalization occur in people older than 65.[267] In contrast, the CDC estimates that with 2009 H1N1, approximately 90% of hospitalizations and 88% of estimated deaths from April through December 12, 2009, occurred in people younger than 65 years old.[268] The comparison of the 2008 Flu Season and the 2009 H1N1 Flu Season is depicted in Figure 12.[269] The figure shows the increase in the new H1N1 flu and the peak two peaks in the Spring and Fall 2009.

[266] Centers for Disease Control and Prevention. (2010, February). H1N1 Flu. Retrieved from 2009 H1N1 Flu ("Swine Flu") and You: http://www.cdc.gov/h1n1flu/qa.htm.
[267] Ibid.
[268] Ibid.
[269] Brammer, L. (2011). Surveillance for Influenza during the 2009 Influenza A (H1N1) Pandemic- United States, April 2009-March 2010. *Clinical Infectious Diseases*, S27-S35.

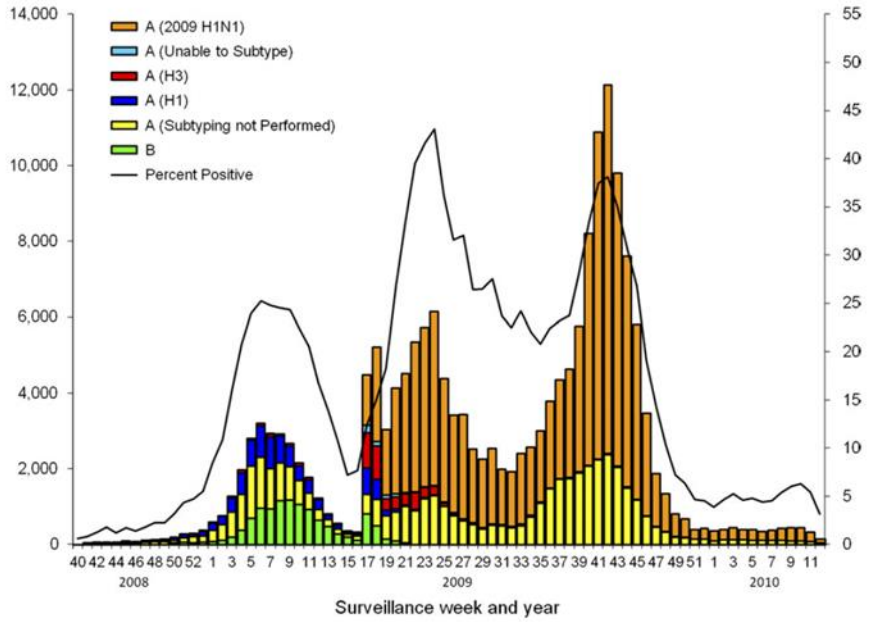

Figure 12 Outbreak Cycle of H1N1 from 2008 - 2010

During the 2009 H1N1 outbreak, again the world was tested with an easily transmittable person-to-person disease that quickly spread using aircraft as the vector. On April 12, the General Directorate of Epidemiology in Mexico reported to the Pan American Health Organization (PAHO) an outbreak of influenza like illness in a small community in the state of Veracruz.[270] Almost a week later, on April 18, 2009, the United States reported to the WHO and the PAHO, 2 cases of a novel swine-origin influenza virus in California.[271] On April 25, New York City officials reported an investigation into a cluster of influenza-like infection in a high school; and shortly after that cases were

[270] Centers for Disease Control and Prevention. (2009, April 30). Outbreak of Swine-Origin Influenza A (H1N1) Virus Infection --- Mexico, March--April 2009. Retrieved from Morbidity and Mortality Weekly Report (MMWR): http://www.cdc.gov/mmwr/preview/mmwrhtml/mm58d0430a2.htm.
[271] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.

reported in Kansas and Ohio.[272] On June 11, the WHO signaled that a global pandemic of 2009 H1N1 influenza was underway.[273] At the time, more than 70 countries had reported cases of this new type of flu.

During the H1N1 outbreak, air travel was considered the main culprit for the global pandemic. Several studies documented not only the travel of infectious patients from the initial Mexican origin to other countries, but also in-flight transmission. One New Zealand study was able to trace their initial cases of H1N1 to a group of students who spent three weeks in Mexico in April 2009.[274] This study determined that 4 passengers contracted H1N1 and all had been seated within two rows of confirmed symptomatic travelers.[275] A Chinese study also documented in-flight transmission of H1N1, but also documented the impact of close contact. In a group of 31 members of a tour group in China, the index case was a female tourist from the United States with confirmed H1N1 that became symptomatic approximately 23 hours after departure to her Chinese tour in Jiuzhaigou.[276] She, in turn, infected 9 (30%) tour group members who had talked directly to her during the tour and one airline passenger within 2 rows of her.[277] This illustrates a case of how close contact may occur in other places outside of in-flight transmission.

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[272] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.
[273] Ibid.
[274] Baker, M. (2010). Transmission of pandemic A/H1N1 2009 influenza on passenger aircraft: retrospective cohort study. BMJ - British Medical Journal, 340, 1-7.
[275] Ibid.
[276] Han, K. (2009). Lack of Airborne Transmission during Outbreak of Pandemic (H1N1) 2009 among Tour Group Members, China, June 2009. Emerging Infectious Diseases, 15(10), 1578 - 1581.
[277] Ibid.

By June, all 50 states in the United States, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands had reported cases of H1N1 for a total of over 1 million cases.[278] The number of cases doubled worldwide from mid-June 2009 to early July 2009.[279] In response, from the end of April 2009 until May 2009, the countries of Argentina, China, Cuba and Peru, enforced bans of all direct flights from Mexico.[280] The CDC closed out reporting of H1N1 in May 2010 when the flu activity reached normal summertime levels.[281] By that time, H1N1 infected over 200 million worldwide with the United States suffering approximately 61 million cases and over 12 thousand deaths.[282]

The H1N1 outbreak of 2009 did test the World Health Organization (WHO) and their most recent implementation of policy based on the lessons learned from the outbreak of SARS. In both cases, however, the disease had spread across international borders before the disease was recognized and before travel alerts were put in place. In May 2009, the WHO did not recommend travel restrictions related to the outbreak of the H1N1 virus and stated that "limiting travel and imposing travel restrictions would have very little effect on stopping the virus from spreading, but would be highly disruptive to

[278] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.
[279] Ibid.
[280] Bajardi, P. (2011, January). Human Mobility Networks, Travel Restrictions, and the Global Spread of 2009 H1N1 Pandemic. PLoS ONE, 6(1), e16591-e16591.
[281] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.
[282] Shrestha, S. (2011). Estimating the Burden of 2009 Pandemic Influenza A (H1N1) in the United States (April 2009 - April 2010). Clinical Infectious Diseases, 52(S1), S75 - S82.

the global community."[283] However, the WHO did issue international travel alerts, and in response, 14 countries issued health travel warnings advising people against non-essential travel to Mexico; subsequent analysis thus showed a 6% drop in international travel to Mexico during the H1N1 pandemic.[284] Post-pandemic analysis, however, showed that the observed decline in air travel to and from Mexico was of too small a magnitude to impact the international spread of H1N1.[285]

Despite the relative ineffectiveness of thermal imagery during SARS, it was again implemented sporadically by a number of countries during the H1N1 outbreak in 2009. In China, the early response strategy was "containment" of the disease, which included temperature screening and administration of health questionnaires at international ports of entry, isolation of infected travelers, and quarantine of close contact of infected persons. However, in finding China's index case of H1N1 into the country, Chinese officials determined that the patient did not truthfully inform health authorities of her symptoms on her entry health questionnaire. Also, on the same flight that had 9 other H1N1 cases, patients did not have symptoms until after returning to China. No one was detected by airport screening.[286] Similarly, Singapore implemented an H1N1 containment phase in April 2009 before any known cases of H1N1 were identified in the country. Containment measures included airport questionnaires and thermal scanners. Dedicated ambulances

[283] World Health Organization. (2009, May 1). World Health Organization. Retrieved from WHO / No rationale for travel restrictions: http://www.who.int/csr/disease/swineflu/guidance/public_health/travel_advice/en/index.html.
[284] Bajardi, P. (2011, January). Human Mobility Networks, Travel Restrictions, and the Global Spread of 2009 H1N1 Pandemic. PLoS ONE, 6(1), e16591-e16591.
[285] Ibid.
[286] Han, K. (2009). Lack of Airborne Transmission during Outbreak of Pandemic (H1N1) 2009 among Tour Group Members, China, June 2009. Emerging Infectious Diseases, 15(10), 1578 - 1581.

were used to take suspected cases to hospitals for further screening.[287] Studies determined that airport screenings were able to detect 12% of all cases, and may have helped in the early stages of the Singapore outbreak. However, within two months, Singapore transitioned from containment to mitigation phase, as the disease had spread across the country.[288] An analysis of patient interviews found that approximately 25% of those with H1N1 boarded a plane after becoming ill and traveled despite having symptoms. This illustrates the ability to travel and gamble with the notion that entry and exit procedures may not accurately find diseased individuals. Overall, for H1N1, the practice of entry and exit procedures was again found to be an ineffective strategy. An analysis showed that even if the sensitivity and specificity of the imaging technology used to detect influenza were perfect, only approximately 4% - 17% of infected individuals could be detected and isolated at the airport.[289] These and several other studies have shown that thermal imaging for the screening of the sick individuals is relatively ineffective.[290] Empirical data may be used to identify key timelines when enhanced entry and exit measures could be keys in stopping the importation of a disease and thus slowing the pandemic.

The H1N1 epidemic was so widespread, that quarantines were not enacted; however, other methods of communication and education seemed to have had some effect. In Mexico, on April 27, 2009 (less than two weeks from the first outbreak in

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[287] Mukherjee, P. (2010). Epidemiology of Travel-associated Pandemic (H1N1 (2009 Infection in 116 Patients, Singapore)). Emerging Infectious Diseases, 16(1), 21-26.
[288] Ibid.
[289] Cooper, B. (2009). Human Movement Patterns and the Spread of Infectious Diseases. *Research on the Transmission of Diseases in Airports and on Aircraft.* Washington D.C.
[290] Priest, P. (2011). Thermal Image Scanning for Influenza Border Screening: Results of an Airport Screening Study. *PLoS ONE*, e14490; 1-7. & Bitar, D. (2009). International Travels and Fever Screening During Epidemics: A Literature Review on the Effectiveness and Potential Use of Non-Contact Infrared Thermometers. *Eurosurveillance*, 1-4.

Veracruz), the Mexican government decreed the closure of all schools in Mexico City and incoming and outgoing airport passengers were informed of the outbreak.[291] Mexico further instituted "1) disseminating educational messages regarding respiratory hygiene through mass media; 2) distributing masks and alcohol hand sanitizers to the public; and 3) discouraging large public gatherings, including church services, theater events, and soccer games."[292] In Israel, the Ministry of Health instituted a containment phase which included recommendations transmitted through television, radio, and internet for voluntary quarantines for all passengers arriving from Mexico.[293] In the United States, CDC provided a steady stream of information to audiences across the spectrum: including a 24-hour information hotline, press briefings, dissemination through health alert networks, daily postings to the CDC 2009 H1N1 website, regular updates on Facebook and Twitter, and a national travelers' health public awareness campaign.[294] Further, numerous print materials in 14 different languages were made and were downloaded tens of thousands of times with additional material that targeted special audiences that included Native Americans, African Americans, Hispanics, pregnant women, young adults, first responders, and health care workers.[295] Between April 2009 when H1N1 flu first emerged and April 2010, CDC held 60 related media events, responded to more than 211,000 related inquiries from the general public and health care providers, and the CDC

[291] Centers for Disease Control and Prevention. (2009, April 30). Outbreak of Swine-Origin Influenza A (H1N1) Virus Infection --- Mexico, March--April 2009. Retrieved from Morbidity and Mortality Weekly Report (MMWR): http://www.cdc.gov/mmwr/preview/mmwrhtml/mm58d0430a2.htm.
[292] Ibid.
[293] Grotto, I. (2009). Swine Flu A/H1N1 Transmission Via the Aviation Sector. *Research on the Transmission of Disease in Airports and on Aircraft.* Washington D.C.
[294] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.
[295] Ibid.

2009 H1N1 website had more than 219,595,000 page views. The number of CDC Facebook fans rose to more than 55,000 fans and the CDC emergency profile on Twitter was tracked by more than 1,200,000 followers.[296] However, again it is unknown the exact impact of the messages across the world or how it may have impacted the disease spread. The H1N1 pandemic demonstrated that despite years of apparent preparations, the public health, government and research communities were still not ready to respond to the challenge of dealing with a fast-moving unique disease outbreak.[297]

In summary, the H1N1 outbreak instituted some of the lessons learned from SARS; however, some of the same unproductive public health measures were implemented that resulted in the same ineffective result. Like SARS, the WHO did not institute any travel restrictions because the disease had spread before it was properly identified. Any travel restrictions were considered ineffective. H1N1 also showed that the WHO definition of close contact may need to be expanded as there were many cases of transmission in the aircraft but also in public spaces. Though, entry and exit thermal procedures identified more cases than SARS, its 12% detection rate did not significantly impact the spread of H1N1. Like SARS, however, the public seem to respond favorably to open communication with measurable increases in social media use. Officials also instituted public health preventative measures such as masks and hand sanitizers that also seem to have impacted the containment of H1N1. Some of these lessons learned were implemented with the threat of Ebola in 2014.

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[296] Centers for Disease Control and Prevention. (2010, June 16). The 2009 H1N1 Pandemic: Summary Highlights, April 2009-April 2010. Retrieved from H1N1 Flu: http://www.cdc.gov/h1n1flu/cdcresponse.htm.

[297] Infanti, J. (2013). A literature review on effective risk communication for the prevention and control of communicable diseases in Europe. Stockholm: European Centre for Disease Prevention and Control.

2014 Ebola

Ebola, previously known as Ebola hemorrhagic fever, is a rare and deadly disease caused by infection with one of the Ebola virus strains. Ebola is caused by infection with a virus of the family Filoviridae, genus Ebolavirus. Ebola was first discovered in 1976 near the Ebola River in what is now the Democratic Republic of the Congo. Since then, outbreaks have appeared sporadically in Africa. The natural reservoir host of Ebola virus remains unknown; however, bats are believed to be the most likely reservoir.[298] An Ebola outbreak began in December 2013 in the Gueckedou district of Guinea, and by April 2014 migrated to the neighboring countries of Liberia and Sierra Leone. By August 2014, the cases rose to over 2240 with approximately 1230 deaths.[299] In the United States, there were two imported cases and two locally acquired cases.

The CDC confirmed the first US travel-associated case of Ebola (the index case) from West Africa to Dallas, Texas. That patient passed away of Ebola on October 8. Two health care workers who had cared for the index patient tested positive for Ebola, recovered and were discharged.[300] The second imported case occurred on October 23, when a medical aid worker who volunteered in Guinea was hospitalized in New York City with Ebola. The patient recovered and was discharged from the hospital on November 11, 2014. Since then the CDC continued to monitor close contact patients and no other cases have occurred from possible exposure to the patient.

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[298] Centers for Disease Control and Prevention. (2014, December). *About Ebola Virus Disease*. Retrieved from Ebola (Ebola Virus Disease): http://www.cdc.gov/vhf/ebola/about.html.
[299] Briand, S. (2014, September 25). The International Ebola Emergency. The New England Journal of Medicine, 1180 - 1183.
[300] Centers for Disease Control and Prevention. (2015, April). *Questions and Answers on Ebola*. Retrieved from Ebola (Ebola Virus Disease): http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/qa.html.

In the West African Ebola outbreak, no in-flight transmission of Ebola had occurred. However, in response to the Ebola outbreak, and in abundance of precaution, airlines contacted passengers who were on the same flight as the original Liberian national who came back from Africa and died in Dallas. After confirmation that one of the nurses that he infected flew from Dallas to Cleveland, the airlines also contacted the passengers on those planes. None of the passengers that flew with the Liberian national or with the nurses were diagnosed with Ebola. The CDC on their "Ebola Guidance for Airlines" Website stated that "the risk of spreading Ebola to passengers or crew on an aircraft is low because Ebola spreads by direct contact with infected body fluids. Ebola does NOT spread through the air like flu."[301]

The Ebola crisis that started in 2014 is the largest in history with approximately 26,000 total cases across the globe and nearly 11,000 deaths. The disease has been largely confined to the countries of Liberia, Sierra Leone, and Guinea. However, the WHO recommended that there should be no general ban on international travel or trade. The WHO announced that "a general ban is likely to cause economic hardship, and could consequently increase the uncontrolled migration of people from affected countries, raising the risk of international spread of Ebola."[302] However, several countries did restrict travel from those affected countries. African nations, (including Nigeria and Senegal), Asian and West Hemisphere countries (including Canada) imposed travel bans

[301] Centers for Disease Control and Prevention. (2014, October 15). Ebola Guidance for Airlines. Retrieved from Quarantine and Isolation: http://www.cdc.gov/quarantine/air/managing-sick-travelers/ebola-guidance-airlines.html.
[302] World Health Organization. (2014, October 23). Statement on the 3rd meeting of the IHR Emergency Committee regarding the 2014 Ebola outbreak in West Africa. Retrieved from Media Center: http://www.who.int/mediacentre/news/statements/2014/ebola-3rd-ihr-meeting/en/#.

on those individuals coming from Sierra Leone, Liberia, and Guinea.[303] Senegal took the additional step of shutting its southern land border with Guinea.[304] One study concluded that flight cancelation and restrictions reduced scheduled commercial air traffic capacity to and from Liberia by 51%, Guinea by 66%, and Sierra Leone by 85%.[305]

Despite not recommending travel restrictions, the WHO established entry procedures in September 2014 in response to the Ebola outbreak. The WHO specified that countries with Ebola transmission should conduct exit screening of all persons at international airports, seaports and major land crossing for unexplained fever. At a minimum, the screening included a questionnaire, temperature measurement, and an Ebola assessment if a fever was detected.[306] The WHO recommended strong exit screening in the countries of the intense Ebola transmission which include Guinea, Liberia, and Sierra Leone. In the United States, the US Department of Homeland Security implemented temperatures screenings at the 5 international airports of New York JFK, Newark, Dulles, Atlanta, and Chicago, for all travelers arriving from Guinea, Liberia, and Sierra Leone.[307] These passengers received a "Check and Report Ebola" (CARE) Kit. CARE Kits included: 1) information about Ebola, 2) a thermometer and health log to check temperature and look for symptoms each day for 21 days, 3) a cell phone with at

[303] Adler, L. (2014, October 31). Factbox - Travel bans issued in reaction to Ebola. Retrieved from Reuters: http://uk.reuters.com/article/2014/10/31/uk-health-ebola-travelban-idUKKBN0IK2G820141031.
[304] Ibid.
[305] Bogoch, I. (2015, Jan). Assessment of the potential for international dissemination of Ebola virus via commercial air travel during the 2014 West African outbreak. LANCET, 385(9962), 29-35
[306] World Health Organization. (2014). WHO Interim Guidance for Ebola Event Management at Points of Entry. World Health Organization.
[307] US Department of Homeland Security. (2014, October 21). News. Retrieved from Statement by Secretary Johnson on Travel Restrictions and Protective Measures to Prevent the Spread of Ebola to the United States: http://www.dhs.gov/news/2014/10/21/statement-secretary-johnson-travel-restrictions-and-protective-measures-prevent.

least 21 days of unlimited talk and text service to make sure the traveler and the health department can stay in contact, and 4) information about who to call if symptoms develop.[308] Travelers who passed through these first two steps of screening could continue their trip if they did not have a fever or other Ebola symptoms and had not been exposed to Ebola. These travelers were connected with a health department at their final destination for active monitoring.[309] However, in assessing potential damage of travel restrictions, another study found that travel restrictions postponed the spread of Ebola to other continents by at most a few weeks, but the restrictions imposed heavy logistical constraints on the management of the epidemic in the countries severely hit by the disease.[310]

In the cases of Ebola, several countries enacted quarantine policies for health care individuals returning from Ebola infected areas. Only one non-military individual was legally quarantined in the United States, but the individual successfully fought and won the court order because she was not symptomatic. She was ordered to maintain constant body temperature vigilance in lieu of the quarantine. By January 2015, several countries declared the end of the Ebola outbreak including Spain, the United States, Mali, as well as the African countries of Nigeria and Senegal.

In the case of Ebola outbreak, the internet was once again the primary means of communication. The CDC created an Ebola website that contained information for

[308] Centers for Disease Control and Prevention. (2015, June 17). Fact Sheet: Screening and Monitoring Travelers to Prevent the Spread of Ebola. Retrieved from Ebola (Ebola Virus Disease): http://www.cdc.gov/vhf/ebola/travelers/ebola-screening-factsheet.html.
[309] Ibid.
[310] Poletto, M. (2014, October 23). Assessing the impact of travel restrictions on international spread of the 2014 West African Ebola epidemic. Retrieved from Rapid Communications: http://www.eurosurveillance.org/images/dynamic/EE/V19N42/art20936.pdf.

travelers, health care workers, parents, and school officials in various forms such as audio, video, flipbooks, fact sheets, banners, posters, and brochures. It also had a specific section that was directly aimed at an audience from West Africa.[311]

The outbreak in West Africa continued with problems arising in risk communication across the African continent. It has been reported that the poor infrastructure, including poor roads and telecommunication networks of West Africa was a barrier to communication; thus various traditional and non-traditional communication tools were used to try to fight Ebola.[312] Newspapers, radio, radio dramas, and television broadcasted almost constant Ebola-related messages and discussions both locally and nationally in Guinea, Liberia and Sierra Leone.[313] Radio was particularly important in the region as a study in 2011 estimated that 86% of women listened to the radio in Sierra Leone, 81% in Liberia and 74% in Guinea.[314] The radio programs were specifically designed to counter the overwhelming 'what not to do' messages during the outbreak with a focus on what people could do to prepare, to stop the virus spreading and to respond if someone around them did get infected.[315] Instant messaging services served as important tools for informal information sharing, with both helpful and damaging effects. People used them to take part in large group discussions where information from official briefings, press releases, and news articles was shared, however, with the instantaneous

[311] Centers for Disease Control and Prevention. (2015, May 1). Communication Resources. Retrieved from Ebola (Ebola Virus Disease): http://www.cdc.gov/vhf/ebola/resources/index.html.
[312] Smout, E. (2015, April 29). Communicating in a crisis like Ebola: Facts and figures. Retrieved from Sci Dev Net: http://www.scidev.net/global/disease/feature/communicating-crisis-ebola-facts-figures.html.
[313] Ibid.
[314] Ibid.
[315] Ibid.

methods of social media, the risk of spreading misinformation was extremely high.[316] In contrast, research conducted in Liberia found that, while community leaders believed they understood basic messages on the virus and its transmission, they also said they had not been given advice on how the outbreak may affect their daily lives; especially in dealing with people they know who were affected with Ebola.[317] A report on the "Ebola Interim Assessment Panel" conducted by the WHO determined that the "traditional cultural practices, including funeral and burial customs, contributed to virus transmission, yet culturally sensitive messages and community engagement were not prioritized. Essentially, bleak public messaging emphasized that no treatment was available; this reduced communities' willingness to engage."[318] The report further concluded that "WHO failed in establishing itself as the authoritative body on communicating about the Ebola crisis, failed to engage proactively with high-level media, and was unable to gain command over the narrative of the outbreak. This weakness had repercussions for many areas of the response; a better approach to communications could have improved confidence in WHO and reduced levels of fear and panic."[319]

In summary, the Ebola outbreak also executed some of the lessons learned from SARS and H1N1. However, travel restrictions and entry procedures (especially in the United States) were added that proved to be very costly without identifying a single case of Ebola. Though it was recognized that Ebola did not have the same transmission rate as SARS and H1N1, and that in-flight transmission was considered to be non-existent, the

[316] Smout, E. (2015, April 29). Communicating in a crisis like Ebola: Facts and figures. Retrieved from Sci Dev Net: http://www.scidev.net/global/disease/feature/communicating-crisis-ebola-facts-figures.html.
[317] Ibid.
[318] World Health Organization. (2015). Report of the Ebola Interim Assessment Panel.
[319] Ibid.

United States still chose to use quarantine measures that were costly and inefficient. The media was directly involved in disseminating information about the transmission of Ebola and may have helped to lessen the panic from its initial stages. These lessons learned will ensure that disease transmission is contained and proper measures are instituted depending on the type and transmission of the disease, and risk of infection.

CHAPTER 4: DISEASE OUTBREAK MODELS

This dissertation used the Spatio-Temporal Epidemiological Modeler (STEM) in the confines of a compartment theory to model four disease outbreaks, specifically SARS, H1N1, Ebola, and pneumonic plague. It models the spread of the diseases and the impact of air travel for the four diseases of interest. The equations used within the compartment model provided the foundation of the model to appropriately compare the threat of disease spread while maintaining many characteristics constant.

Compartment models are used to illustrate disease spread using known disease parameters as well as known environmental factors while controlling for variables. Each person in a population is accounted for in a compartment, and no one person may be in more than one compartment at any given time. Transitions between compartments are driven by differential equations. The disease characteristics define the number of possible compartments and the equations that account for the movement of individuals between compartments.

All the disease of interests for this dissertation were modeled using an "S" – "E" – "I" – "R" model where each person in a population is in a state of Susceptibility (S), Exposed (E), Infectious (I), or Recovered (R). The compartments and transition rates for pneumonic plague are pictured in Figure 13.

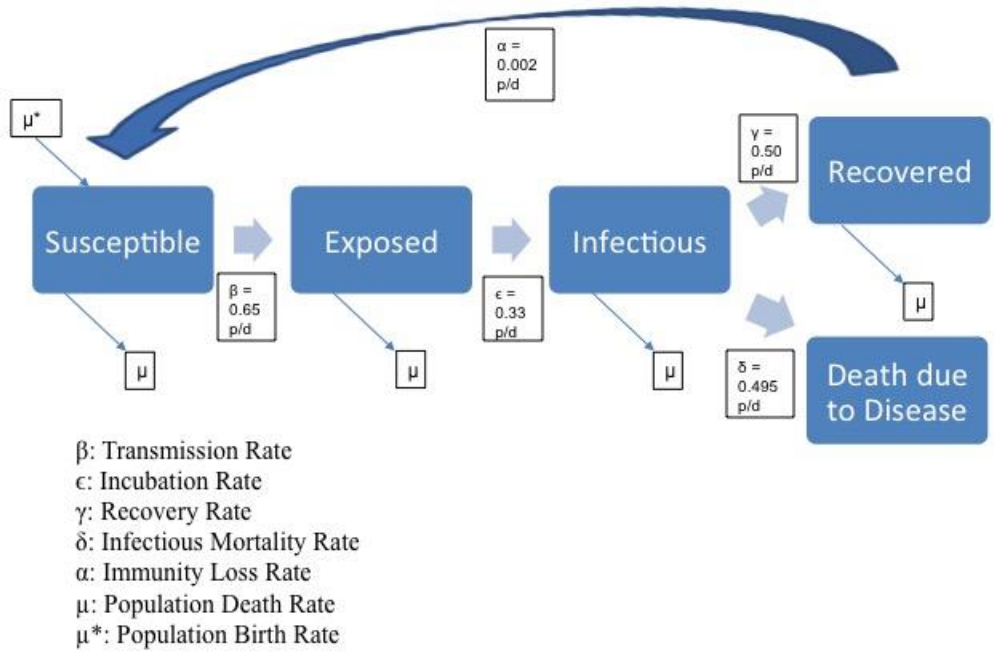


Figure 13 Pneumonic Plague Compartment Model with Transition Rates

In this model, a person is born and instantly susceptible to the disease and enters the "S" state. It is possible that a person is incapable of becoming infected, or was immunized against a particular disease and thus are not part of the susceptible compartment in other diseases. In the case of H1N1 in 2009, the disease was a novel strain that no one in the population had been immunized against. In the case of SARS, Ebola, and pneumonic plague, there is no known natural immunity, nor is there any currently used immunization. The entire population is assumed to be susceptible before an outbreak.

An assumption in this dissertation was that the population death rate (μ) equaled the birth rate (μ*) in the susceptible compartment. However, the death rate will continue to impact all individuals within all the compartments regardless of the disease affecting the population. Newly born individuals enter only in the susceptible compartment. Thus, the assumption is that natural death and births will not affect the rate at which the disease impacts the population, thus they are equaled in the model. The compartment model is considered closed, thus the population is static with no new individuals coming or going except in the case of natural death or disease death. In this dissertation, μ = μ* in the susceptible compartment eliminating any potential of population changes impacting the disease spread. The death and birth rates were maintained constant across all the diseases of concern. The rate in this constant population was set at an average span of 72 years depicted in Equation 1.

Equation 1 Compartment Model Death Rate

$$\boldsymbol{\mu = 1/72\ years}$$

$$\mu = 1/26298 days$$

$\mu = 0.000038$ person/day (p/d)

A person may remain in "S" or become exposed "E" if they come in contact with an infectious individual or vector carrying the disease of concern. The transmission rate is represented by β taking into account the natural characteristics of the disease and historical epidemiological findings of disease spread and transmission. The R_o (Basic Reproductive Ratio) of an infection is the number of infectious cases one single infected

case generates, on average, over the course of its infectious period in an uninfected population. In relation to the transmission rate, R_o, is the ratio of the transmission rate (β) to the total rate at which individuals leave the infectious (I) compartment. Thus, R_o is the ratio of the transmission rate divided by the recovery rate. If R_o is known, then it can be used to calculate the transmission rate when the infectious recovery rate (γ) is also known. The equation for the infectious recovery rate (γ) in pneumonic plague is depicted in Equation 2. The Infectious Recovery Rate (γ) is defined as the rate at which population members in the "I" infectious state, who do not die, will recover.

In the case of pneumonic plague, the published value of the average number of new cases generated by each case (R_o) = 1.3. The average time that person would be infectious is approximately 2 days. Given the infectious recovery rate, the transmission rate (β) for pneumonic plague is calculated in Equation 3.

Equation 2 Infectious Recovery Rate (Pneumonic Plague)

$$(\boldsymbol{\gamma}) = \boldsymbol{1"infectious"\ person\ (who\ will\ recover)/x\ days}$$
$$(\gamma) = 1"infectious"\ person\ (who\ will\ recover)/2\ days$$
$$(\gamma) = 0.5 \text{ person/day (p/d)}$$

Equation 3 Transmission Rate (Pneumonic Plague)

$$(\boldsymbol{Ro}) = (\boldsymbol{\beta})\ /(\boldsymbol{\gamma})$$
$$(Ro) = (\beta)\ /0.5\ person/day$$
$$1.3 = (\beta)/0.5\ person/day$$
$$(\beta) = 0.65 \text{ person/day (p/d)}$$

After a certain incubation period, the individual moves to the "I" state in which that person becomes infectious and infects others at a particular rate. In a compartment model, the incubation rate is defined as the rate which population members in the "E" exposed state enter the "I" infectious state. For example in the case of pneumonic plague, the average incubation period is 3 days. The incubation rate for pneumonic plague is depicted in Equation 4.

Equation 4 Incubation Rate (Pneumonic Plague)

$$(\epsilon) = \mathbf{1}''\boldsymbol{exposed}''\ \boldsymbol{person/x\ days}$$
$$(\epsilon) = 1''exposed''\ person/3\ days$$
$$(\epsilon) = 0.33 \text{ person/day (p/d)}$$

For each disease, all individuals exposed are assumed to eventually move to the infectious compartment based on the average incubation time for each disease. Any deaths not caused by the disease during the outbreak time are negligible and assumed to be at the same rate between each of the diseases being studied. The population has the same rate of non-disease deaths irrespective of the disease being modeled.

During the illness, the time a person spends in "I" is considered the average time of the illness, and the rate at which a person moves from the "I" stage to the "R" state is depicted as (γ) referred in Equation 2. In contrast, the Infectious Mortality Rate (δ) is defined as the rate in which population member in the "I" infectious state, who will eventually die, do die. In the case of pneumonic plague, the fatality rate of approximately

99% is taken into account for the overall infectious mortality rate and is depicted in Equation 5. This assumes no intervention has been taken.

Equation 5 Infectious Mortality Rate (Pneumonic Plague)

$$(\boldsymbol{\delta}) = \boldsymbol{Fatality\ Rate/x\ days}$$
$$(\delta) = 0.99/2\ days$$
$$(\delta) = .495 \text{ person/day (p/d)}$$

Finally, the immunity loss rate (α) is defined as the rate at which the population members in the recovery state lose their immunity and re-enter the susceptibility state. Except in the cases of H1N1, all the diseases of concern do not have a lifelong immunity nor do they have immunization against future exposure. H1N1 has been added to the annual influenza vaccine. It is assumed that a person who recovered from SARS, H1N1, Ebola, or pneumonic plague will not immediately be re-infected after recovery. This dissertation sets the immunity for one year, assuming that a person will not contract the same disease within the same year, and not be susceptible again within the same outbreak timeframe of 6 months. The immunity loss rate of one year is depicted in Equation 6.

Equation 6 Immunity Loss Rate

$$(\boldsymbol{\alpha}) = \boldsymbol{1"recovered"\ person/x\ days}$$
$$(\alpha) = 1"recovered"\ person/365\ days$$
$$(\alpha) = 0.0027 \text{ person/day (p/d)}$$

Scenarios

The IBM Spatiotemporal Epidemiological Modeler (STEM) version 2.0.3 was used to set up the scenarios. The scenarios were created with the same baseline models to analyze the disease spread of each of the pathogens of interest. The scenarios and baselines are summarized in Table 3. Table 4 outlines the disease characteristics used for each of the four pathogens. The results of each of the equations are presented in the Appendix along with screen shots as entered in the STEM program.

Table 3 Summary of Baseline Scenarios

Summary of Baseline Scenarios				
Diseases	SARS	H1N1	Ebola	Pneumonic Plague
Compartments Analyzed	Infected	Recovered	Deaths Caused by Disease	
Transportation	Air (International, Interstate, Intrastate)	Ground (Roads)		
Initial Infections	1	10		
Common Scenarios to all Models				
Arrival Location	JFK International Airport, Queens, New York			
Time Frame	1 Sept 2016 - 1 March 2017			
Population	US Human Population (State, Country, City) = Initial Susceptible Compartment			

Models

The disease characteristics, compartments analyzed, initial infections, and transportation modality were all changed, compared and contrasted to answer the research questions within the STEM model.

Diseases

First, the diseases of interest were modeled: 1) SARS, 2) H1N1, 3) Ebola, and 4) Pneumonic Plague. Based on the equations previously outlined, each of the diseases had a Basic Reproductive Ratio (R_o), average infectious time, Incubation Rate (ϵ), Infection Recovery Rate (γ), Case Fatality Rate, and Infectious Mortality Rate (δ) based on the data of previous outbreaks, historical epidemiological numbers, and scientific evidence. The ranges of disease characteristics are depicted in Table 1 in Chapter 1: Introduction. However, an average number was taken in those cases where a range of values was noted in the past. For example, Table 1 shows a transmission potential or basic reproductive ratio (R_o) of SARS as 2-3 new cases generated by each case. In this dissertation, 2.5 was used as the R_o. This approach may underestimate or overestimate the transmission rate of the disease in comparison to an actual event. However, taking an average approach to all the values will compare the diseases in a typical scenario without accounting for extremes. The results and final values used for this dissertation for each disease are outlined in Table 4. The screenshots of the numbers inputted for each disease in STEM are illustrated in the Appendix (Reference Figure 24 through Figure 27).

Table 4 Biological Modeling Parameters of Diseases

SEIR Model	SARS	H1N1	Ebola	Pneumonic Plague
Average # of new cases generated by each case (R_o)	2.5	2.45	1.75	1.3
Average Infectious Time (Period of Illness)	21 days	10 days	15 days	2 days
Transmission Rate (β)	0.119	0.245	0.117	0.650
Incubation Rate (ϵ)	0.14 (7 days)	.25 (4 days)	0.1 (10 days)	0.33 (3 days)
Infection Recovery Rate (γ)	0.05	0.10	0.07	0.50
Case Fatality Rate (without intervention)	28%	0.16%	70%	99%
Infectious Mortality Rate (δ)	0.013	0.00016	.047	0.495
Immunity Loss Rate (σ)	0.0027 (365 days)	0.0027 (365 days)	0.0027 (365 days)	0.0027 (365 days)

Compartments analyzed

The compartments analyzed for each of the 4 diseases included the number of individuals infected ("I" compartment), those individuals who have recovered ("R" compartment), and those who died from the disease thus ending the "Death Due to Disease" compartment. The total numbers of individuals in the in the "I", "R", and "Death Due to Disease" compartments would equal the number of cases of a disease at any given time period. Those in the "R" compartment would eventually lose their immunity at a rate of 0.0027 person/day, which equates to approximately 1 year as depicted in Equation 6.

Transportation

The baseline scenarios were created with the same parameters to analyze the natural progression of each of the four pathogens. In this dissertation, individuals arrive at John F Kennedy International Airport (JFK) in Queens County, New York, USA. JFK airport is the 5th busiest airport in the United States, and a common entry point from many international locations.[320] STEM uses the 2007 US Department of Transportation Research and Innovative Technology Administration Bureau of Transportation Statistics (RITA-BTS) on individual tickets as outlined and described in Lessler.[321] The airline data used are a sample of 10% of US full travel tickets which accounts for layovers from reporting air carriers.[322] Also, the 2004 ground transportation data creates a rate of transportation between the states and counties of the United States used as statistics of typical ground transportation. The ground transportation and airline transportation used are baseline rates from an open-source data set available to the developers and all users of STEM. In order to answer the research question, "What is the role of air travel in disease transmission as a vector for humans while carrying an infectious disease," disease spread was modeled with and without air travel while maintaining ground transportation.

Initial infections

Initial infections would model entry into the United States through JFK airport by passengers carrying the disease that may have arrived from an area of the country or another country in which the disease may have originated. The number of passengers was

[320] Renzulli, M. (2016, Aug 30). The 25 Busiest Airports in the USA. Retrieved from USA Travel: About Travel: http://usatravel.about.com/od/Plan-Your-Trip/tp/Busiest-Airports-In-The-USA.htm.
[321] Lessler, J. (2009, February). The Cost of Simplifying Air Travel When Modeling Disease Spread. PLoS ONE, 4(2), e4403.
[322] Ibid.

varied and modeled to determine the effects of the number of initial cases on the outbreak and account for the possibility of several passengers from a similar area starting the outbreak of the disease. Two initial case scenarios were modeled. First, one individual is considered the index case and determines the effect when only one passenger is infected. This passenger may start the infection at the airport or while starting a visit in Queens, New York. Secondly, 10 passengers are modeled who are exposed to a disease by either in-flight transmission or traveled from an outbreak area to arrive in New York to start the US infection. Those passengers would either continue travel domestically by road or by air, or stay in the New York. All would be transmitting the disease in accordance with the transmission rate of the diseases outlined in Table 4.

Common models

The following models within the scenario are maintained constant in order to eliminate any seasonal or population variation that may impact disease spread. The control of these parameters creates an understanding of the impact of the disease characteristics instead of the impact of the migration of the population or the change in the temperature. The control of the models allows the analysis of the differences between the diseases instead of the differences between the country populations or the impact of the environment. Though real life mirrors stochastic models which allows for random changes, to understand the impact of diseases within the context of this dissertation, the factors of season and population must remain constant.

Time frame

The scenario starts with the individuals arriving on 1 September 2016. The scenarios ran for 6 months ending on 1 March 2017. This corresponds to a natural flu season where any of these pathogens may be initially mistaken for the seasonal flu.

Population

Administrative levels correspond to geographical divisions of a country. A level 0 administration identifies an entire country (e.g. USA). A level 1 administration corresponds to a subdivision of a country which can be a state, territory, parish, or a province. California, Colorado, and New York are all level 1 administrations of the USA. Level 2 administrations are subdivisions of a level 1 administration. Orange County, Monterey County, and Napa County are all level 2 administrations that belong to California. Within STEM, an open-source population model at the Level 2 administration level is used to account for all the variations of a population at the county level.[323] Level 2 population accounts for all individuals starting in the Susceptible Compartment "S" verified against the 2000 US population as 281,421,906 individuals.[324]

Overall, the baseline scenarios of SARS, H1N1, Ebola, and pneumonic plague were compared against each other. The results controlled for variables including population count and air travel; thus the diseases have a natural spread based on disease biological characteristics in a controlled model. The Appendix visualizes the baseline spread of each of the scenarios with total infection of individuals across the US after 30, 60, 90, 120, and 150 days (Reference Figure 28 through Figure 39). Each of following

[323] Kaufman, J. (2016, Apr 30). STEM Design Document. Retrieved from Spatio-Temporal Epidemiological Modeler: http://wiki.eclipse.org/STEM_Design_Document#Nodes.
[324] US Department of Commerce. (2011). Population Distribution and Change. Retrieved from Census.gov: https://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf.

assumes the start of 1 or 10 infectious individuals arriving at JFK Airport, Queens, NY on 1 September and spreading for the next six months.

Results

All the graphical and numerical results indicate that SARS and H1N1 have a much greater impact in terms of infections and deaths than Ebola or pneumonic plague. Furthermore, air travel only impacts the location of the disease cases and not the rate at which the disease causes infections or death. The Appendix visually depicts spread of infections of the four diseases in screenshots of 30, 60, 90, 120, and 150 days (Reference Figure 28 through Figure 33 for maps depicting 1 initial case and reference Figure 34 through Figure 39 for maps depicting 10 initial cases). The spread of disease may be seen in SARS and H1N1, and nothing is shown in Ebola or pneumonic plague whether the disease started with 1 or 10 initial cases. The number of infectious cases for Ebola and pneumonic plague are too small to depict on a visual map it without artificially increasing the scale of the maps; both for 1 or 10 initial infected cases. However, quantitative results may be seen in Table 5.

In comparing the 6-month spread of SARS, H1N1, Ebola, and pneumonic plague, Figure 14 compares the three diseases controlling for the number of cases. H1N1 (as the first column) displays much higher cases of infections, recoveries, and disease deaths through time with only 1 index case as compared to the other 3 diseases. Figure 15 provides similar results with 10 index cases. Figure 40 and Figure 41 within the Appendix show the same results depicting the outcomes by disease.

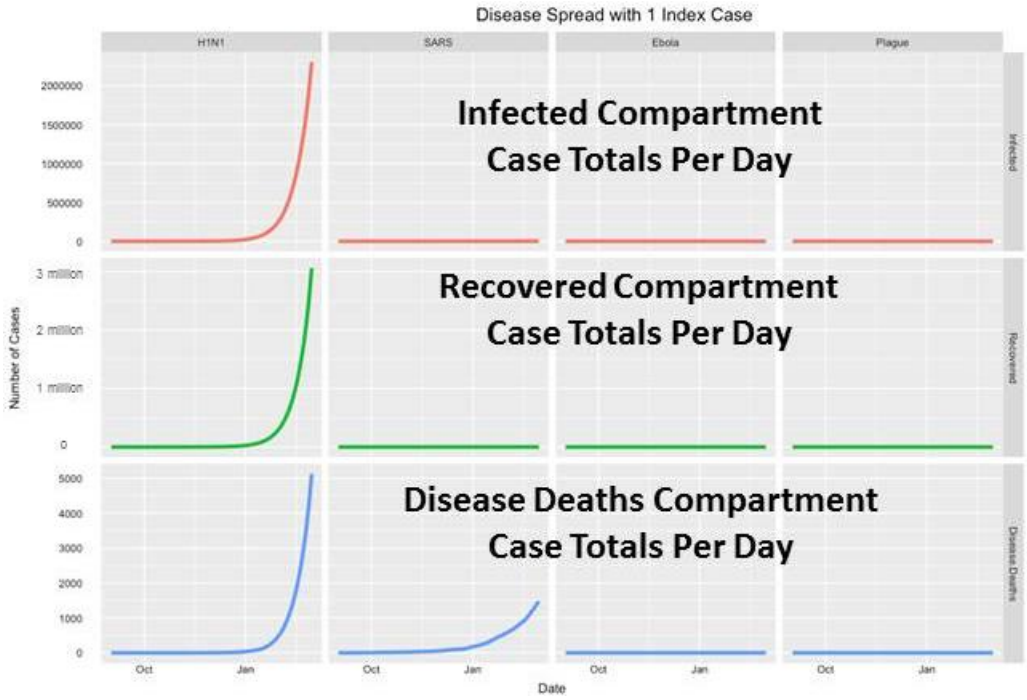


Figure 14 Compartment Case Totals Per Day Per Disease, 1 Index Case

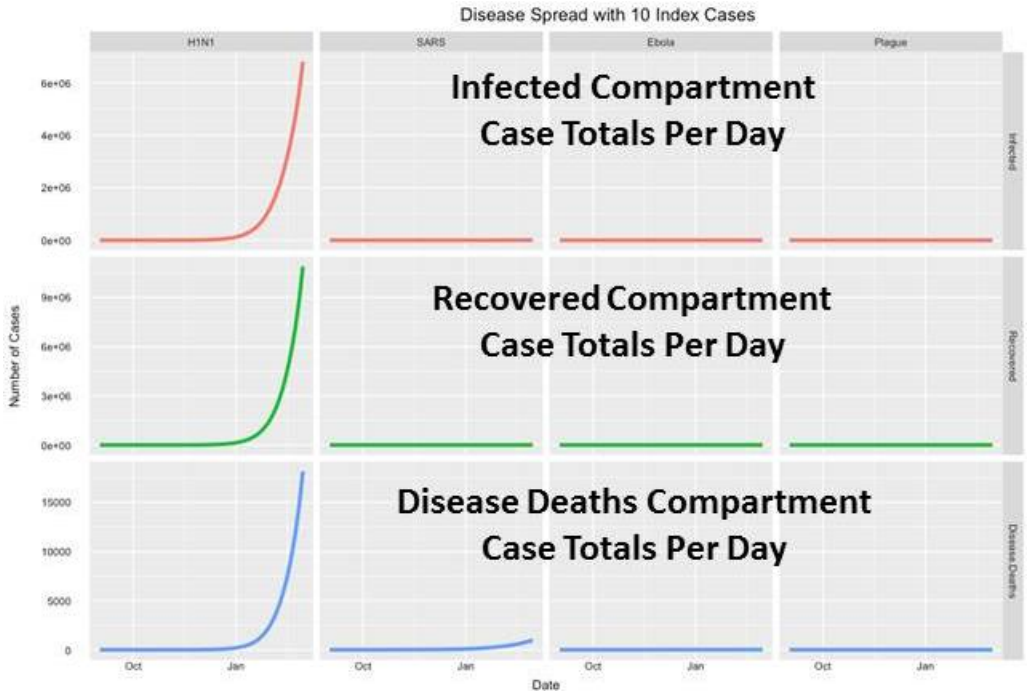


Figure 15 Compartment Case Totals Per Day Per Disease, 10 Index Cases

After 6 months, the model predicts, with initial cases of 10 individuals in New York City that over 7,000 individuals will be infected with SARS, 18 million with H1N1, 43 with Ebola, and 25 with Plague. The deaths after 6 months include 1,000 for SARS, over 18 thousand for H1N1, 19 for Ebola, and 13 for plague. All of these results assume a natural flow of disease based on biological characteristics and population movement, and do not account or assume any public health interventions. The full results of the modeling predictions for index cases of 1 or 10 initial individuals after 6 months of disease spread are seen in Table 5.

Table 5 Simulated Disease Cases and Deaths at the End of 6 Months

Diseases	Number of Initial Infections	Total Number of Disease Cases After 6 Months	Total Number of Deaths After 6 Months
SARS	1	4,042	572
SARS	10	7,279	1,000
H1N1	1	5,617,702	5,374
H1N1	10	18,363,550	18,856
Ebola	1	5	1
Ebola	10	43	19
Plague	1	1	1
Plague	10	25	13

In comparison with the historical accounts of SARS, H1N1, Ebola, and pneumonic plague, the hypothetical scenarios of each of the disease spread follow similar patterns and results. Though the United States experiences a small number of SARS cases, and no SARS deaths, its neighboring country of Canada did experience 438 cases

and 44 deaths.[325] The US historical comparisons of disease cases and deaths as well as from other countries of note are outlined in Table 6.

Table 6 Historical Comparison of Disease of Interest

Historical Diseases	Total Disease Cases	Total Deaths	Population
2003 SARS US[326]	27	0	281,421,906 (US 2000 Census)[327]
2003 SARS Canada[328]	438	44	30,007,094 (Canada 2001 Census)[329]
2003 SARS China[330]	5327	349	1,284,530,000 (China 2002 Census)[331]
2009 H1N1 US (Apr – Oct 2009)[332]	~ 22 million	~3,900	281,421,906 (US 2000 Census)
2014 Ebola US[333]	4	1	308,745,538 (US 2010 Census)[334]
2015 Plague* US[335]	11	3	308,745,538 (US 2010 Census)
*Cases of plague in the Unites States were classified as bubonic plague. No person to person transmission was reported.			

[325] National Advisory Committee on SARS and Public Health: Canada. (2003). *Learning from SARS.* Ottawa: Health Canada.
[326] Cassels, F. (2012). Severe Acute Respiratory Syndrome. The Jordan Report.
[327] US Department of Commerce. (2011). Population Distribution and Change. Retrieved from Census.gov: https://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf.
[328] National Advisory Committee on SARS and Public Health: Canada. (2003). *Learning from SARS.* Ottawa: Health Canada.
[329] Statistics Canada. (2013, Dec 23). *2001 Census topic-based tabulations*. Retrieved from Population counts: http://www12.statcan.gc.ca/English/census01/products.
[330] World Health Organization. (2003, Dec 31). Summary of probable SARS cases with onset of illness from 1 Nov 2002 to 31 Jul 2003. Retrieved from Emergencies preparedness, response: http://www.who.int/csr/sars/country/table2004_04_21/en.
[331] National Bureau of Statistics of China. (2003). *China Statistical Yearbook.* Beijing: China Statistics Press.
[332] Centers for Disease Control and Prevention. (2009, November 12). *H1N1 Flu*. Retrieved from CDC Estimates of 2009 H1N1 Influenza Cases, Hospitalizations and Deaths in the United States, April – October 17, 2009: http://www.cdc.gov/h1n1flu/estimates/April_October_17.htm.
[333] Centers for Disease Control and Prevention. (2015, April). *Questions and Answers on Ebola*. Retrieved from Ebola (Ebola Virus Disease): http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/qa.html.
[334] US Department of Commerce. (2011). Population Distribution and Change. Retrieved from Census.gov: https://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf.
[335] Centers for Disease Control and Prevention. (2015, Aug 28). *Human Plague - United States, 2015*. Retrieved from Morbidity and Mortality Weekly Report: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6433a6.htm?s_cid=mm6433a6_w.

Table 7 combines the results of Table 5 and Table 6 and calculates the disease cases and the number of deaths in each real or hypothetical scenario against the population. All the hypothetical cases of SARS, H1N1, Ebola, and Plague have similar impacts to the population with H1N1 affecting the most individuals with approximately 7% of the population getting infected and SARS affecting 0.002% of the population. Both Ebola and pneumonic plague, whether real-world or in a hypothetical scenario, show that only a very small percentage of the population will be affected. After the 6-months the initial cases of Ebola and pneumonic plague will most likely have died, and no further spread of the disease is expected.

Table 7 Actual and Hypothetical Cases Impact to the Percentage of the Population

Historical Diseases	Total Number of Disease Cases	Total Number of Deaths
2003 SARS US	27 0.0000096%	0 0.0000000%
2003 SARS Canada	438 0.0014597%	44 0.0001466%
2003 SARS China	5327 0.0004147%	349 0.0000272%
2009 H1N1 US (Apr – Oct 20090	~ 22 million 7.8174440%	~3,900 0.0013858%
2014 Ebola US	4 0.0000013%	1 0.0000003%
2015 Plague US	11 0.0000036%	3 0.0000010%
Hypothetical Modeled Cases		
SARS-1	4,042 0.0014363%	572 0.0002033%
SARS-10	7,279 0.0025865%	1,000 0.0003553%
H1N1-1	5,617,702 1.9961850%	5,374 0.0019096%
H1N1-10	18,363,550 6.5252738%	18,856 0.0067003%
Ebola-1	5 0.0000018%	1 0.0000004%
Ebola-10	43 0.0000153%	19 0.0000068%
Plague-1	1 0.0000004%	1 0.0000004%
Plague-10	25 0.0000089%	13 0.0000046%

The comparative results of each of the four modeled diseases with the historical accounts show the importance of the disease characteristics and the impact of the infectious rate as a factor of basic reproductive ratio. A disease that has a long illness such as SARS and H1N1 is expected to cause a higher natural spread than diseases in

which the period of illness is brief. In the cases where the period of illness is brief such as pneumonic plague, those individuals do not have the same opportunities to infect others as those diseases with a longer period of illness. The results are expected based on scientific evidence and mirror closely to recent disease outbreaks.

Question: What is the role of air travel in disease transmission as a vector for humans while carrying an infectious disease?

The model results illustrate the threat and risk of SARS and H1N1 without intervention. In determining the impact of air travel, all the models were recreated with all the same parameters sans the spread of disease through air travel. This compared all the diseases, yet illustrates the impact if all airline travel was stopped and only ground transportation remained. All of the diseases, SARS, H1N1, Ebola, and pneumonic plague had negligible difference in the number of infected, recovered, or deaths as illustrated by the graphs in the Appendix (Reference Figure 42 through Figure 45). Since all the variables remained intact, the transmission rate in all the diseases would continue to infect individuals at its normal rate within the susceptible population. The individuals that were infected continued to infect those in the local area or within the area most connected by ground travel.

The most significant impact was the location of the infected individuals. The Figures below illustrate the spread of disease infection for H1N1 removing the air travel. The side by side comparison shows the location of infection individuals (depicted in red). Figure 16 through Figure 19 illuminates the infected individuals with ground only transportation on the left side, and air and ground transportation on the right. The disease spread is shown in screenshots of the United States map at the 60, 90, 120, and 150 days.

Eliminating air travel would confine the disease to the local area, but would not impact the number of infected, recovered or deaths. The Appendix (Figure 46 through Figure 51) illustrates the location impact of ground-only disease spread for all the diseases of interest, SARS, H1N1, Ebola, and pneumonic plague. As shown, the impact is only seen in diseases with a significant spread namely SARS and H1N1. Though Ebola and pneumonic plague could travel from one area of the country to another through air travel, the number would be very small as the initial infection even with air travel is extremely small. The risk of disease would be negligible with Ebola and pneumonic plague with or without air travel.

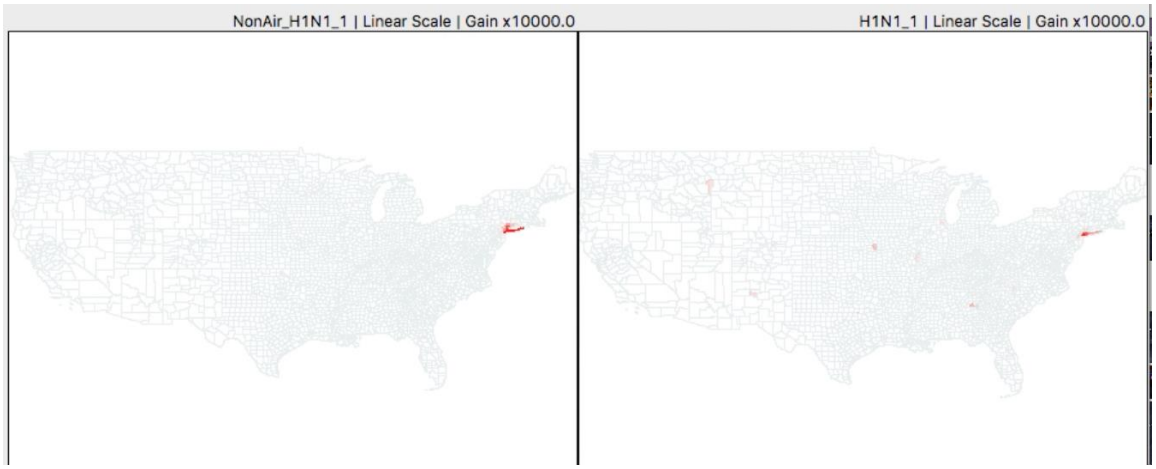


Figure 16 Comparison of Non-Air Travel vs Air Travel Model for H1N1 (60 Days)

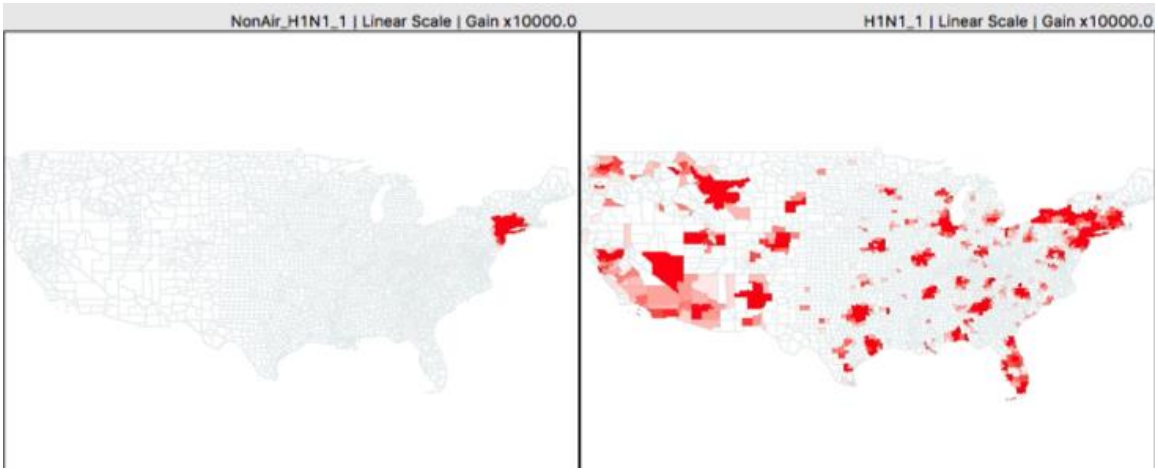


Figure 17 Comparison of Non-Air Travel vs Air Travel Model for H1N1 (90 Days)

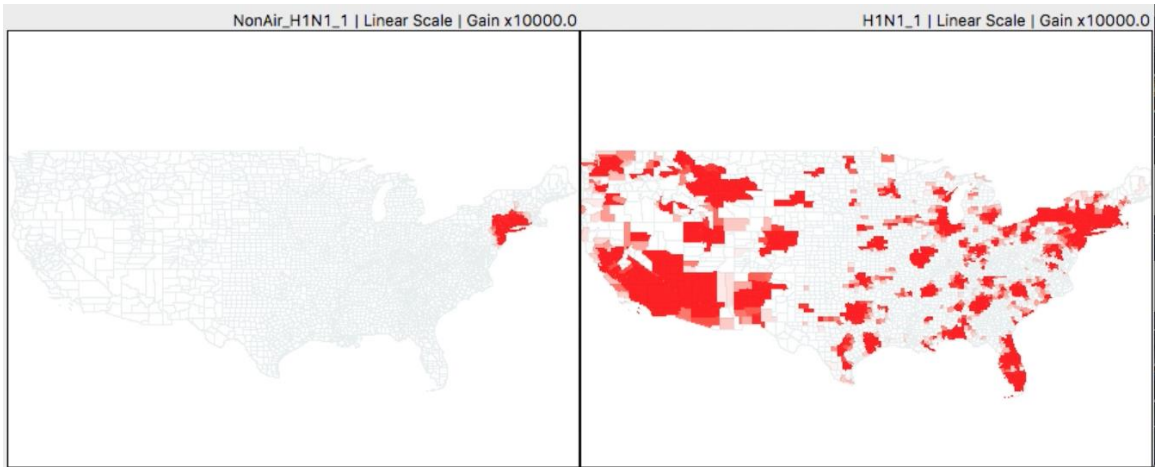


Figure 18 Comparison of Non-Air Travel vs Air Travel Model for H1N1 (120 Days)

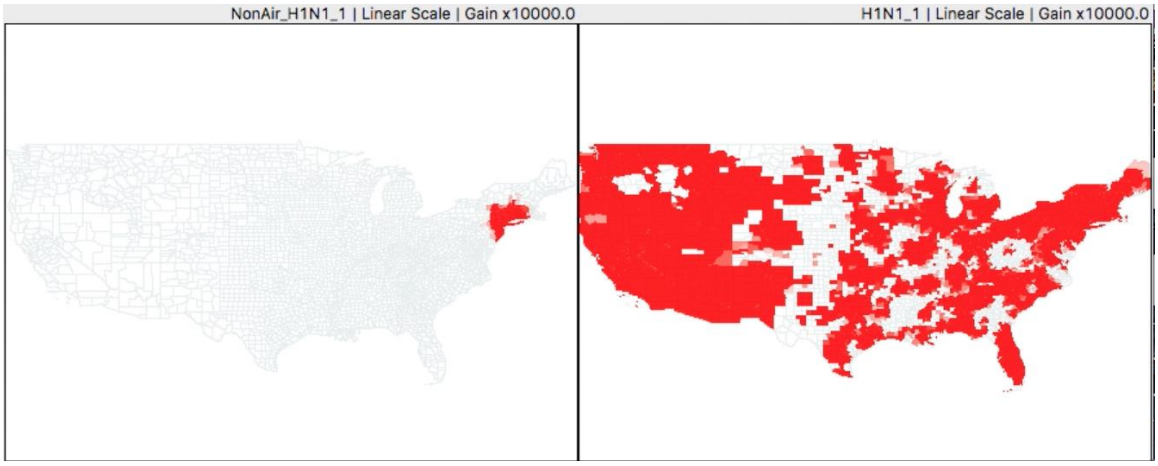


Figure 19 Comparison of Non-Air Travel vs Air Travel Model for H1N1 (150 Days)

Question: What is the threat of a pneumonic plague outbreak across the United States in a natural form or in an aerosolized bioterrorist attack?

In the case of pneumonic plague, even if 10 individuals arrived on an aircraft from an infected location, the model showed that the outbreak would not last and that the deaths were attributed primarily to the originally infected individuals and secondary close contact individuals. Even in a very conservative model, the threat of pneumonic plague is not from the disease. Within the model, one person infected with pneumonic plague is expected to be the only person to be infected and die. The threat of in-flight transmission or airport transmission would be minimal.

Even in the event of a bioterrorist attack, the models show that with no interventions, the deaths would be attributed to the initial number infected and disease spread would be minimal. Table 8 and Figure 20 show the impact of pneumonic plague should a bioterrorist attack be successful in infecting 1, 10, 50, 100, or 1000 individuals. Figure 20 shows similar patterns in disease infection extinction as the disease dissipates naturally through time. In Table 8, a pneumonic plague initial infection of 10 individuals

would see the last of the infections in approximately 2 weeks, assuming no interventions. A successful bioterrorist attack that was able to infect 1000 individuals all at once would cause approximately 2640 infections and 1400 deaths. It would be about 2 months before new infections are nonexistent. This is assuming no medical intervention in the first month, and thus an unrealistic scenario especially within the United States.

Table 8 Predictive outcomes of bioterrorist attack using pneumonic plague

Number of initial pneumonic plague infections	Days until number of infections reach zero	Predicted total number of infections	Predicted total number of deaths
1	1 day	1	1
10	15 days	25	13
50	33 days	135	71
100	40 days	269	143
1000	65 days	2640	1431

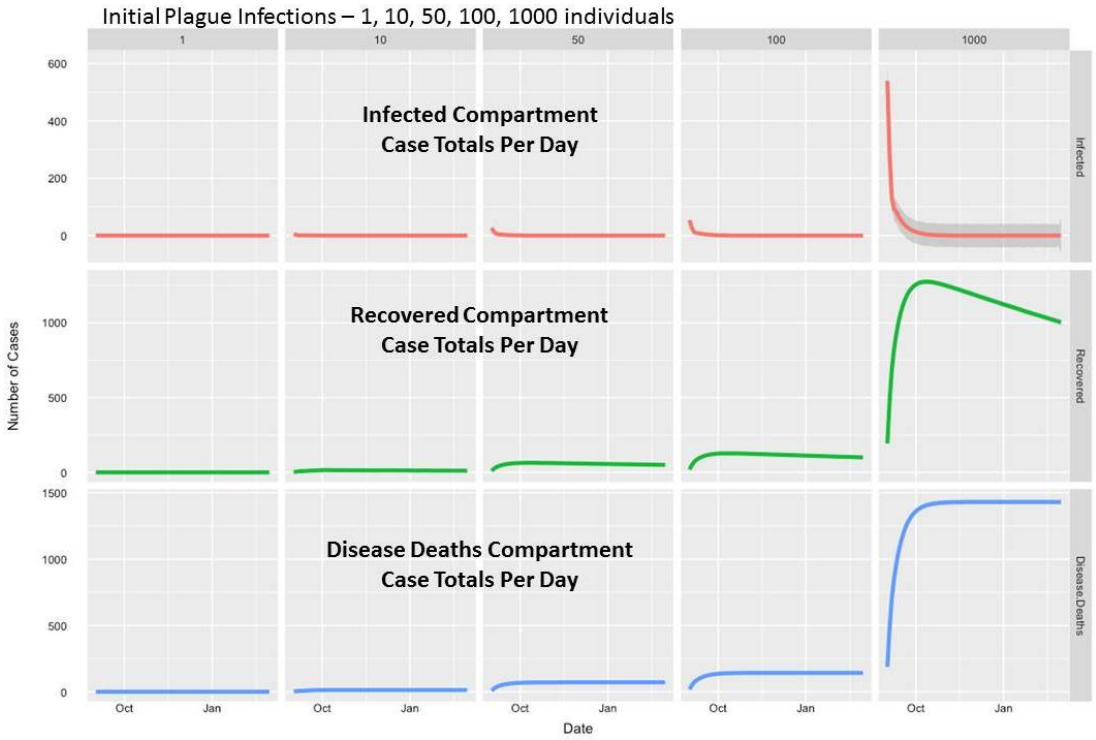


Figure 20 Comparison of Pneumonic Plague outbreak with Initial Infections due to Bioterrorism

Plague is not a sustainable pathogen and a poor choice to use for a threat of a wide-spread disease spread. An attack, even if clandestine, would become obvious as a multiple of individuals suspiciously die within 2-3 days. At that time, interventions will minimize further infections and curtail the risk of death with prophylaxis and antibiotic treatments. A suicide infector would not have the capacity to start a major US infection, even if that person would be successful in infecting 1 other individual. The models show that a person with pneumonic plague gets infected and dies in such a short amount of time that the disease outbreak is not sustainable.

Threat of pneumonic plague: natural

The threat of plague has not been seen in a wide-spread deadly form since the early 1900s. Medical science has improved both the prevention and treatment of plague. Since scientists were able to isolate the bacterium *Y. pestis* and determine the role of the rats and human transmission of the disease, containment procedures have helped in preventing another worldwide disaster. Research has also determined that cold, crowded, and unsanitary conditions facilitated the transmission of primary or secondary pneumonic plague. The improvement in hygienic conditions and the use of antibiotics have been able to contain all recent pneumonic plague outbreaks.

The United States had one of its last outbreaks in Los Angeles between 1924 and 1925. However, since antibiotics have started to become a major part of treatments, all plague outbreaks within the United States have been successfully contained.[336] In the most recent plague threat in India in 1994, where over 1000 suspected cases of pneumonic plague afflicted the city, city officials started social distancing procedures including closing all public gathering places, including schools, restaurants, movie theaters, and parks.[337] Antibiotics were widely distributed and efforts to kill rats and fleas led to the containment of the disease within a few short weeks.[338]

Modeling shows that the threat of pneumonic plague is minimal, and should not be a major air travel concern if an individual becomes infected and travels. In comparison to the natural progression of other diseases with air travel as a constant, the United States

[336] Giblin, J. (1995). When Plague Strikes. New York: Harper Collins Publishers.
[337] Roul, A. (2003). Plague Outbreaks in India: Surat and Himachal Pradesh. In P. Chari (Ed.), *Biological Weapons Issues and Threats* (pp. 115-137). New Delhi: India Research Press.
[338] Barnes, K. (2014). Social vulnerability and pneumonic plague: revisiting the 1994 outbreak in Surat, India. Environmental Hazards, 13(2), 161-180.

faces substantially more threats of SARS and H1N1 versus Ebola and pneumonic plague. This is evidenced and verified by the United States actual experience with the diseases. The United States faced several dozen cases of SARS, and no deaths, though it was wide-spread in China. The United States faced several million cases of H1N1, and over 12,000 deaths. The United States only had 4 cases of Ebola and one death, with no person to person transmission. In the hypothetical case of pneumonic plague (as modeled), pneumonic plague would cause an outbreak similar to the US Ebola experience.

Due to the rapid progression of pneumonic plague and the high likelihood of death without treatment, individuals die in a short period of time minimizing the exposure to other individuals keeping the spread of the disease from continuing. This scenario is consistent with current historical evidence, as pneumonic plague remains a viable medical threat: each year approximately 20 US cases are reported of plague, with less than 10% progressing to the pneumonic plague form or starting as its primary form. A case of person to person transmission has not occurred in over 90 years in the United States. Due to the rapid progression of pneumonic plague within an individual, the risks and chances of an infectious person with pneumonic plague traveling are minimal. An individual would be very ill to travel and may be deterred from traveling. If a person has not progressed to a very ill state, the risk of person to person transmission within the aircraft is very low. If a diseased individual did travel, that person may export the disease from one area to another area possibly risking others for infection. However, even in the new location, an individual would fall ill and have minimal exposure to individuals thus minimizing a potential sustained outbreak. In all the scenarios of 1 or 10 individuals

getting infected, the models show no sustained progression of pneumonic plague and essentially all the deaths are attributed to the first infected individuals and to some individuals directly in close contact with patient zero. A natural progression of outbreaks with pneumonic plague should be considered a very low likelihood and a non-threat.

This conclusion has also been verified in other studies that model pneumonic plague. Gani concluded that "larger outbreaks rarely exceeded more than a hundred cases. Of course, this assumes relatively small numbers of initial index cases and prompt and efficient public health interventions (transmission tends to zero immediately following outbreak detection)."[339] Furthermore, Gani concluded, "the key element in the control of smaller outbreaks of primary pneumonic plague would be the acuity of disease surveillance systems and quick detection of outbreaks, the efficiency of which might depend significantly on the number of persons initially infected."[340] Once a plague is identified, the outbreak begins to immediately die off. The key to survivability is improved detection.

Threat of pneumonic plague: bioterrorism

Plague has been studied as a bioterrorist weapon and been used in the bubonic form in the early centuries. The United States studied it as a weapon but terminated the unsuccessful program in the 1970s; US scientist could not grow the germ in bulk. One leading US scientists claimed that "we could grow it in high concentrations for laboratory work…but in large-scale quantities, it lost its ability to infect."[341] It is theorized that the

[339] Gani, R. (2004). Epidemiological Determinants for Modeling Pneumonic Plague Outbreaks. Emerging Infectious Diseases, 10(4), 608-614.
[340] Ibid.
[341] Orent, W. (2004). *Plague.* New York: Free Press.

reason for the unsuccessful use of aerosolized *Y. pestis* would be its susceptibility to environmental conditions.[342] No bioterrorist group seems to be able to protect the bacterium from dying before its successful dissemination. British bioterrorist experts theorized that as pneumonic plague progressed as a disease, the plague would kill the individual before developing infectious coughs or airborne particles that may infect others, thus natural pneumonic plague would naturally die.[343] The fact remains that an infected individual dies very quickly and does not have an effective infectious period as SARS or H1N1 thus the spread of pneumonic plague is minimized.

If a successful bioterrorist aerosol attack was to occur and resulted in 50 or 100 individuals infected in an airport or within the confines of an airplane, even the natural flow of the disease is minimal. This scenario would suggest a breakdown in the normal air transportation security measures. There is no precedent for any individual successfully constructing or deploying an aerosolized attack of *Y. pestis*. However, should that scenario occur, it is likely that the indication and realization of a bioterrorist attack would be high and individuals exposed would be quickly quarantined resulting in minimal secondary exposure and a quick containment of disease progression. Deaths of the original infected personnel would be high, but a continued disease outbreak would be non-existent.

Even if the attack were a clandestine aerosolized attack and a natural progression of disease in 50 or 100 victims, the STEM modeling shows that an outbreak would last approximately 40 days with the deaths limited to the first individual exposed. Deaths

[342] Orent, W. (2004). *Plague.* New York: Free Press.
[343] Ibid.

would be quickly realized in the first couple of days, and once public health interventions take place the outbreak is likely to be reduced to only a couple of weeks. In addition, the ability of pneumonic plague to propagate an epidemic is severely restricted by the requirement for close contact with a dying patient, usually on the last day of the patient's life.[344] Public panic would most likely cause the most anxiety with self-isolation and self-deterrent from air travel or close contact to the area defined as ground zero.

Limitations

In response to any severe global pandemic, scientists look toward modeling as a way to forecast the progress of the disease. The technology exists to rapidly build many new models of infectious diseases. Tools and procedures are needed to compare the accuracy of competing models before relying on any of them to guide policy. Because infectious diseases evolve in a dynamic system, models will never be completely accurate. A "good approximation" requires not only knowledge of the disease parameters themselves, but also an understanding of the most important disease vectors.

The compartment model used in this dissertation is a simplified model to compare one disease to another while controlling for similar variables. This is a deterministic model in order to control for environmental and population data while exploring the characteristics of the diseases. However, in actuality, the reproductive rate of a disease, the incubation rate, recovery rate, and mortality rate can all vary based on socio-economic factors, gender, and age. Each of the characteristics of the disease in question will have a different effect in different populations. However, this dissertation focused on

[344] Butler, T. (2009). Plague into the 21st Century. *Clinical Infectious Diseases, 49,* 736-742.

an average population in the United States, on air travel impacts, and on the policy in controlling the spread of disease based on typical disease characteristics. A more realistic model would be a stochastic model to account for changeability in all the variables. Each interpretation of the model produces a different outcome due to the elements of chance within the variables.[345] These effects are significant when the numbers involved are small and variance becomes important for the results. A deterministic compartment model is used as a laboratory of controlled variables to explain the trends seen between different diseases in a large population.

All of the equations used to define compartment models represent finite difference equations where time is fixed in days or hours. If in reality the variables are changing too rapidly, a compartment model may not accurately represent the change from one compartment to the next.[346] Furthermore, models may over or underestimate certain parameters. This may be the case when individuals are assumed to be exposed with the same probability, which is not realistically the case. For airline travelers, exposure is often related to their purpose for travel, such as visiting friends and interacting with the population versus pure tourist or business travel where exposure may be less.[347] Also, infectious individuals in the model travel at the same rate as non-infectious individuals, which may not be true in real travel conditions. Thus, exposure

[345] Matthews, L. (2005). New approaches to quantifying the spread of infection. Nature Reviews Microbiology, 3 (7), 529-536.
[346] Wearing, H. (2005). Appropriate Models for the Management of Infectious Diseases. PLoS Medicine, 2 (7), 0621-0627.
[347] Johansson, M. (2011, July). On the Treatment of Airline Travelers in Mathematical Models. *PLoS ONE, 6*(7), e22151.

rate may not be as constant as depicted.[348] However, it has been shown that simplified models replicate actual data well in a small area; studies have also shown that the data is not easily extendable to a global scale.[349] Since this dissertation concentrated on the United States and not on the global scale, the model output controlled for similar variables.

The model in this dissertation is purposefully oversimplified, both to reflect modeling choices made in the early days of an outbreak and to focus trends and patterns associated with disease distribution and the influence of air travel. However, King noted in his study, "Avoidable errors in the modelling of outbreaks of emerging pathogens, with special reference to Ebola," that fitting models to cumulative incidence data can lead to bias, underestimation, and overestimate of the uncertainty associated with model parameters.[350] Also, in this type of model, other biases may limit the analyses of the outcomes. The model may overestimate small town travel while at the same time underestimate large city travel. Thus, a disease may reach a small town sooner than expected.[351] However, the model does normalize airline travel for individual diseases and allows for the long distance jump from one coast to another.[352] These limitations in the overall computer modeling and airline travel are minor as the model provides a control of travel among the different disease characteristics depicted in this dissertation. The

[348] Johansson, M. (2011, July). On the Treatment of Airline Travelers in Mathematical Models. *PLoS ONE, 6*(7), e22151.
[349] Ibid.
[350] King, A. (2015). Avoidable errors in the modelling of outbreaks of emerging pathogens, with special reference to Ebola. Proceedings B. The Royal Society Publishing.
[351] Lessler, J. (2009, February). The Cost of Simplifying Air Travel When Modeling Disease Spread. PLoS ONE, 4(2), e4403.
[352] Lessler, J. (2009, February). The Cost of Simplifying Air Travel When Modeling Disease Spread. PLoS ONE, 4(2), e4403.

outcomes are seen in the trends as one disease is compared to another, but the numbers of infectious or deceased are not used as absolutes.

Furthermore, the models assume the pathogens of interest mirror previous outbreaks with known disease features. Disease parameters in this research such as basic reproductive ratio, average infectious time, incubation rate, infection recovery rate, case fatality rate, and infectious mortality rate reflect the same characteristics of historical outbreaks and scientific evidence. If the genetics of any of the diseases are changed by natural mutation or by intentional genetic manipulation, it may dramatically change the outcome of the disease spread. The manipulation of the disease characteristics may change the recommendations if the disease spread or mortality rate was greater than previously observed. This research assumes no manipulation or genetic mutation has occurred and that all disease spread would perform as previous historical outbreaks with expected disease characteristics.

CHAPTER 5: CONCLUSIONS AND POLICY RECOMMENDATIONS

In the event of an infectious disease epidemic, the world must act swiftly, decisively, and united for a cohesive plan based on science to limit the spread of the disease and as well as the panic. Political leadership, public health and transportation officials must cooperate to successfully implement a plan to mitigate disease damage. When officials work side-by-side a disease outbreak may not be prevented, but it may be limited. In cases such as Ebola and pneumonic plague, where the disease of concern does not have a sustainable outbreak, efficient and cost effective measures will limit apprehension while shortening the disease's outbreak timeframe.

The goal is to alleviate public fear while minimizing and preventing further dissemination of the disease. Air travel has boomed in the past century, and continues to be a primary method of transportation, especially to travel quickly across the United States and to other continents. The risk of a traveler spreading a disease increases each year as air travel has become faster and cheaper. If the disease of concern has a high transmission rate such as SARS and H1N1, the spread of disease also increases in speed and dispersal due to flourishing air travel. Officials must implement the tracking and prediction of disease spread as soon as the threat of the disease, whether from a natural outbreak or bioterrorist attack, is identified. Therefore, when an infectious disease

outbreak occurs, it is imperative to already have appropriate travel and communication policies in place.

The results indicate that the risk of infection and death are greater in flu and SARS than the risk of contracting or spreading Ebola or pneumonic plague. The threat of pneumonic plague is not from the disease, but from the potential psychological threat. The models show that a person with pneumonic plague gets infected and dies in such a short amount of time, that the disease outbreak is not sustainable. The threat of in-flight transmission or airport transmission would be minimal. The United States should invest in simple preventive measures and education programs to not only deter terrorists but mitigate the attacks at the lowest level.

The most appropriate responses include streamlining contact procedures for ticketed passengers, an expansion of "close contact" definitions, wide-spread educational and training programs for public health measures and personal habits, as well as very limited entry and exit procedures to limit the spread and panic of a pneumonic plague outbreak. The combination of targeted procedures, along with education may encourage ill passengers to restrict their own travel, thus limiting the outbreak and panic to a local area.

In the age of novel terrorist attacks, response to possible future attacks must be continually updated. Terrorists are finding new ways to showcase their terror. Though currently unprecedented, it is highly probable that the aviation industry will be a target for a biological attack. A bioterrorist attack with aerosolized *Y. pestis* will be very difficult to conduct but in the midst of a historical pattern of potential use and testing,

may be a future agent. Deaths will be limited to those immediately exposed, but due to the high fatality rate, the attack will cause panic in those in proximity to the attack area. Initially, symptoms of pneumonic plague would resemble those of other severe respiratory illnesses. Early identification and treatment of affected individuals and extensive communication measures for all will mitigate a pneumonic plague fear with minimal consequences.

Understanding the public's perception of a disease and the risk factors involved will guide the type of information and education presented. However, several simple concepts will help prepare for the next outbreak of concern (natural or intentional) especially when the disease may be disseminated by airline travel. The public needs to be educated early and empowered with preventative measure techniques. This will reduce panic, increase preventative measure compliance, and diminish the spread of many diseases. Modeling has shown that a natural outbreak or a bioattack of plague cannot be sustained for a long period of time. It will naturally end. Recommendations may serve dual purposes for a natural event or during a bioterrorist attack. Previous research suggests that travel restrictions are ineffective, and may have a higher economic impact than the disease itself. Instead, preventive measures should be put in place in airports and in aircraft to prevent the natural spread of any disease and limit the exposure and deaths in the event of a bioterrorist attack.

The US should be prepared in the event of deadly infectious disease to ensure the safety of the population, to limit economic impact, and to stop any panic. This chapter outlines policy recommendations to implement effective measures should a natural or

intentional outbreak of pneumonic plague occur. The intended audiences for implementing each of the recommendations are identified with the headings. Though these are physical and policy recommendations, they are all rooted in the education of the public. The bottom-line is that any measures must include informing and educating the public. Mitigation measures have also been recommended by an Airport Cooperative Research Program Report 91: Infectious Disease Mitigation in Airports and on Aircraft.[353] That guidebook includes 24 recommended actions for buildings, airplanes, and people.[354] These recommendations based on science should be implemented, in which many recommendation overlap with the research and recommendation presented in this dissertation. Evidence shows that simple measures may improve global travel health. This limits death, minimizes infections, decreases economic impacts, and curtails fear.

[353] Airport Cooperative Research Program. (2013). Infectious Disease Mitigation in Airports and on Aircraft. Washington D.C.: The National Academies Press.
[354] Ibid.

Summary of policy recommendations based on the scientific evidence of this dissertation are outlined in Table 9.

Table 9 Summary of Policy Recommendations

<table>
<tr><th>Global Policy
(WHO, CDC)</th><th>Airline Ticket Sales
(Airline ticketing websites)</th><th>Airports
(International, State, Regional)</th></tr>
<tr><td>Recommendation #1:
Expand the definition of "Close Contact"</td><td>Recommendation #2:
Mandatory health contact information requirement on all ticket purchases</td><td>Recommendation #3:
Passenger airport and pre-boarding self- sanitizing measures</td></tr>
<tr><td colspan="2">Recommendation #4:
Enhanced travel alerts and advisories during ticket sales</td><td>Recommendation #5:
Expand HEPA filters in airports</td></tr>
<tr><td></td><td colspan="2">Recommendation #6:
Limited, announced, random temperature checks</td></tr>
<tr><td colspan="3">Recommendation #7: Specific crisis communication</td></tr>
<tr><td colspan="3">Unique plague recommendation for airports and affected cities:
Recommendation #8: Wide-spread vector termination</td></tr>
</table>

Recommendation #1: Expand the definition of "close contact" (Audience: global policy)

Previous research indicates that the risk of transmission while traveling in an airplane is very low. The aircraft has a protective mechanism while flying including air being re-circulating constantly through HEPA filters and mixed with the outside air. The WHO defines close contact as the same row plus 2 rows ahead and 2 rows behind the identified ill individual. However, close contacts in airport scenarios may prove to be a more likely route of transmission where an individual may be situated next to an ill individual for a long period of time while at the airport. These individuals may in-turn be seated outside the WHO definition of close contact or may not even be on the same aircraft as the ill individual. These airport scenarios include and are not limited to:

1) close contact with individuals at neighboring gates traveling to other destinations, 2) delays and close proximity to travelers in lines at check-in, screening, restrooms, and concessions, and 3) close contact in a confined jet-way space awaiting aircraft boarding. The time and exposure to infectious individuals just before or after a flight may also add to an expanded definition of close contact. In many cases, where individuals are encouraged to arrive at the airport hours before a flight, or in the event of an aircraft delay, it is conceivable that an individual may spend more time at the airport than on the flight itself where non-infected individuals may be exposed to infectious individuals. During this time, an individual may be in close contact with many more individuals outside of an aircraft than while flying. Therefore, by only defining close contact as the space within an airplane, current policies do not account for the many opportunities for infection spread within the airport itself. Future policies must take into account all the individuals on an aircraft and within the timeframe of the exposure window at the airport.

Recommendation #2: Mandatory health contact information requirement on all airline ticket purchases (Audience: airline ticket sales)

The use of a passenger manifest to track down and trace passengers that may have been affected by a diseased individual is not only very resource intensive but also may miss a large population of other close contacts outside of the aircraft. To improve contact information across airport populations, additional mandatory contact requests should be required. Contact information on any airline ticketing process should be mandatory, just as it is to ask for “Date of Birth” and “Gender” on all tickets. Example of mandatory notice on all airline ticket purchases is depicted in Figure 21.

Mandatory: Notification of Disease in Travel Areas, Airports, or Aircraft
Do you wish to be notified of an outbreak of any infectious disease of concern* that have may have been reported in the traveling area, airport, or aboard the aircraft? ☐Yes ☐ No
If yes, contact information must be provided:
☐ Text:
☐ E-mail:
☐ Voicemail:
☐ Other, please provide complete contact information:
All current Travel Alerts may be found at: http://wwwnc.cdc.gov/travel/notices/
* Infectious diseases of concern include: 1) cholera, 2) diphtheria, 3) infectious tuberculosis, 4) plague, 5) smallpox, 6) yellow fever, 7), viral hemorrhagic fevers, 8) SARS, and 9) flu that can cause a pandemic

Figure 21 Example of Mandatory Disease Notice on Airline Ticket Purchases

Streamline contact tracings is necessary as a response to a natural spread of disease or after a biological terrorist attack. If the ticketed passengers at the airport had already given their contact information, a wide spread communication effort could be made to all those with tickets at the airport during the time of the infectious exposure or the bioattack. Airport workers would have contact information through their employers. Family, friends, and other individuals awaiting passengers at the airport may be notified by mass media and word of mouth.

Recommendation #3: Passenger airport and pre-boarding self-sanitizing measures (Audience: airports)

As previously noted in the background section, filters on aircraft and the airflow of functioning and flying aircraft serve as baseline preventive measure for in-flight disease transmissions. However, the effectiveness is compounded when passengers practice infection control techniques. Prior to boarding, the gate may make

announcements to the passengers about the risk of disease in the area that the aircraft is flying into, or flying out of. In either case, this just-in-time education would be fresh in passengers' minds and emphasize the fact the individuals will be in close quarters at the gate, on the jet-way, during the boarding process on the aircraft, and during flight. Airlines and airports should distribute hand sanitizers and face masks. Just as the passengers embark the aircraft, and while their boarding pass is being scanned, gate officials should be encouraging all to use hand sanitizers and expand personal space on the jet way. These immediate instructions would increase compliance. At the same time, airport employees should remind passengers to cover their coughs with hands or elbows. These low-cost preventive measures may minimize pathogen transmission before the aircraft doors are closed.

As previously noted, public fear may present valuable windows for intervening in habit formation. If airports institute hand sanitizers that are visible and accessible to the public, especially at restroom entrances, at the gate area before boarding an aircraft, at all food court locations, at the entrances of all the airport stores, in all the lounge areas, and randomly around all the corridors, the public would not only feel safer but may delay the onset of all other disease spread such as the seasonal flu. Gate officials should make a habit of making announcements to remind passengers to sanitize their hands. The airport could make random announcements encouraging individuals to sanitize their hands as they move through the airport. It is important to note that the announcements are not only targeted to passengers, but airport workers and visitors. All should partake in the

preventative measures. This continuous emphasis in good habits may start a culture trend not just during a panic, but at all times.

Recommendation #4: Enhanced travel alerts and advisories during ticket sales (Audience: global policy and airline ticket sales)

The use of mandatory statements on airline purchases also bring to the forefront to every passenger the thought of limiting personal travel to areas of concern as well as limiting personal travel during an illness. Travel restrictions have been found to be minimally effective and must be strictly enforced to be successful. Historical data indicates they may only cause a slight delay in infectious disease introduction to the US. Studies suggest that it is more cost effective to inform the public about the various resources in order for them to make a more informed choice. Notices of health concerns should be displayed while buying a ticket on-line, on the phone, or at a ticket counter.

Example of notice during airline ticket purchase is depicted in Figure 22.

WARNING: TRAVEL AREA HAS HEALTH ALERT FOR PLAGUE!
All current Disease Travel Alerts and Advisories may be found at: http://wwwnc.cdc.gov/travel/notices/
Do not travel if suspected of carrying a disease of concern!*
* Infectious diseases of concern include: 1) cholera, 2) diphtheria, 3) infectious tuberculosis, 4) plague, 5) smallpox, 6) yellow fever, 7), viral hemorrhagic fevers, 8) SARS, and 9) flu that can cause a pandemic

Figure 22 Example of Health Notice During Airline Ticket Purchase

Education is an important tool in the arsenal to contain infectious diseases from spreading globally. The Aerospace Medical Association Task Force recommends "that brief and easily understandable, relevant health information be provided to passengers

going into or departing from a WHO notified area of infectious diseases."[355] The notices would be from major health agencies declaring a health advisory including the WHO and the CDC. During the SARS epidemic, the CDC developed new designations of travel alerts and travel advisories.

"A **travel alert** is a notification by CDC that an outbreak of a disease is occurring in a geographic area. Its purpose is to provide information to travelers and resident expatriates about the status of an outbreak, how to reduce their risk for infection, and what to do if they become ill. The risk for individual travelers is thought to be definable and limited. In contrast, a **travel advisory** recommends against nonessential travel to an area because the risk to travelers is considered to be high as a result of ongoing transmission or inadequate containment. The travel advisory not only provides information about the status of an outbreak, but also is intended to reduce the risk for exposure by decreasing the volume of traffic to the affected area."[356]

The differences between a travel alert and a travel advisory will help clarify the impact of the disease of concern and reduce misconceptions. A travel alert in combination with education of proper preventative measures would reduce the risk of infection. On the other hand, a travel advisory provides a stronger message to the public of avoiding exposure to a region. A strong message may trigger the public to further find information about a disease and their risk of contraction. In the event of an infectious disease outbreak, clear and concise travel alerts will help in reducing the spread of

[355] Aerospace Medical Association Task Force. (2004). Emerging Infectious Diseases Including Severe Acute Respiratory Syndrome (SARS): Guidelines for Commercial Air Travel and Air Medical Transport. *Aviation, Space, and Environmental Medicine, 75*, 85-86.
[356] Arguin, P. (2004). Health Communication during SARS. Emerging Infectious Diseases, 10(2), 377-380.

infection through air travel. Each of the agencies should declare a notice when scientifically applicable citing references and disseminating that information through various social media outlets and enhancing those messages at the airport and through each ticket sale.

Recommendation #5- Expand HEPA filters in airports (Audience: airports)

Research has indicated the effectiveness of HEPA filters within the aircraft and how the airflow and filtration system of a flying aircraft acts a protective factor against disease dissemination. This same rationale should be provided for expanding the use of HEPA filtration systems in high-traffic areas in all airports. These filters have a 99.9% efficiency rate against most pathogens. The use of HEPA filtration systems may deter a bioterrorist from using the air conditioning system as a dissemination method. Airport officials should advertise the use of the HEPA filtration emphasizing airport and airlines commitment to safety and public health.

Recommendation #6: Limited, announced, random temperature checks (Audience: airline ticket sales and airports)

The world is connected by airline travel with billions of passengers a year and growing. Targeted entry and exit procedures have shown limited effect. However, in a dire situation, these very costly procedures may be a measure of last resort to prevent a deadly disease from spreading. It must be noted, however, that the deadliness of the disease must outweigh the economic and political impact of such a decision. It also would only be effective with complete cooperation of all international airline carriers and

country public health officials. Without buy-in from all nations and commercial airline travel, this measure would ultimately fail.

Limited and announced, yet random, temperature checks during an outbreak may deter ill individuals to travel. Random checks may serve as a deterrent for individuals to postpone travel due to the threat of getting caught, thus causing a delay in travel plans, or the threat of being quarantined and isolated. Individual may re-think unessential travel. Though random thermal screening has many factors and variables, the criteria should be high when referring individuals for further screening. The entry or exit thermal screen would have a high specificity even if sacrificing sensitivity. Only very ill patients who might pose significant risk would be recommended for continued screening, therefore minimizing public inconvenience.

SARS and H1N1 after-action reports determined that thermal screenings had a very low success rate. It caused many millions of dollars in manpower and logistics without a significant delay in disease importation or reduction in the eventual spread of disease. Therefore, the actual thermal screenings may not be cost effective in halting disease spread. However, more importantly, the threat of entry and exit procedures may be enough to deter enough individuals to stop travel that may equal the rate of success from a large scale thermal screening effort.

The alert of potential entry and exit screening during an outbreak while an individual is purchasing tickets to an area of concern may give an individual pause to re-think their travel plans. If an infectious disease such as SARS was detected in New York, then any and all aircraft to and from New York airports may be subjected to random

screening tests. If during the ticketing process, a passenger is alerted of the random check, that person may decide not to purchase the ticket or change their travel plans and destination. Below in Figure 23 is an example of an alert that may show up during an on-line ticket purchase.

****ALERT**** ****SARS Outbreak Concern in New York City**** ****Random Thermal Screening Instituted****
Your travel plans have an aircraft flying to/from JFK Airport, Queen, NY
You may be subjected to random thermal screening due to a suspected outbreak of SARS. If you suspect you are ill, do not travel and delay your travel until fever symptoms have subsided. Please consult a doctor if you have concerns of disease exposure. Do you understand that you may you undergo thermal testing during your travels? ☐Yes ☐ No
Please consult the CDC website for more travel information: http://wwwnc.cdc.gov/travel/notices/

Figure 23 Example of a Thermal Screening Alert on an Airline Ticket

Recommendation #7: Specific crisis communication on the threat of pneumonic plague (Audience: global policy, airline ticket sales, airports)

The groundwork for early containment procedures means constant and relevant communication. Early messages during a disease crisis must educate the public on the medical threats and the risk of traveling in an aircraft. Education of the public is a crucial foundation and probably the most cost efficient and effective way of slowing the spread of disease. Historically, in both cases of SARS and H1N1 outbreaks, public programs significantly slowed disease spread, perhaps more so than other containment efforts. Lessons learned must be applied from the past about communicating effectively with the public.

There is no published information on how the modern day population would react nor is it known if the current political climate could efficiently bring all governments to stop all global airline travel, and implement aggressive technological and educational measures, if necessary. Additional research is warranted on understanding travelers' attitudes toward air travel restrictions and communication to contain the spread of epidemics in the future. Additional research is needed for the various travel scenarios infected patients may encounter that would lead to higher risk of disease transmissions whether prior to travel, at the airport, in the air, as well as arriving at a destination. Lastly, research is needed to describe disease transmissions in aviation travel, disinfecting policies, as well as political and traveler attitudes to help focus policies that may limit a global pandemic.

If an outbreak of pneumonic plague were to occur, communication barriers follow when individuals take advice from a source of their choosing, especially if that source is not an expert. Emergency response officials must provide consistent, accurate, and simple information that can help the public prevent transmission of infectious disease, detect symptoms, and seek treatment so that uncertain individuals do not look elsewhere for information. Messages should provide pertinent and applicable information such as general prevention methods, the differences in the indications of illness, and treatment methods.

In order to guide public health officials, the World Health Organization created a handbook entitled "Effective Media Communications during Public Health Emergencies." This has been the foundation for many countries and local organizations

to guide their instructions in the midst of a crisis. The handbook provides a seven-step process to facilitate media coverage during public health emergencies. Critical tips for effective communication include:

1) Provide early and constant communication and avoid rumors especially from non-credible sources

Individuals will start doing their own research when the rumor of a pneumonic plague outbreak is reported. A search of "Plague" or "Pneumonic Plague" (without a current outbreak) will yield top results from Wikipedia, the CDC, and the WHO. These websites need to have current, relevant and simple information on their top home page as concerned individuals start researching the plague. Potential passengers may also start looking at travel websites, airline home pages, or other sources of information, official or unofficial. The promptness of how and where messages are conveyed may help lessen panic. However, studies have shown that under stress, individuals usually compare current messages to the first pieces of information processed, even if later messages are more accurate.[357] It is imperative that true messages are posted in multiple locations especially common travel websites and news outlets, and written in easy-to-process formats.

2) Simple, honest communication statements created from message maps

The CDC recommends constructing message maps to convey standardized messages that target specific audiences. A message map packages important facts about the disease and the risks of disease spread in simple sentences. This way the audience

[357] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication.

does not have to work to understand the information conveyed. Public relation offices could use message maps to guide their announcements in order to convey honest, trustworthy, and relevant information to potential travelers. As the plague already has a fearsome reputation as the "Black Death," it is essential to provide accurate and easily accessible information. This will help limit potential panic.

Table 10 provides a sample message map concerning the question: "Will I get pneumonic plague on an aircraft to or from an outbreak area?"

Example of a pneumonic plague message map:

Table 10 Pneumonic Plague Message Map

Stakeholder: Public **Question: Will I get pneumonic plague on an aircraft to or from an outbreak area?**		
Key Message 1	**Key Message 2**	**Key Message 3**
Pneumonic plague is extremely difficult to contract from person to person.	Infection rate is extremely low.	It is very difficult to spread pneumonic plague from coast to coast.
Supporting Information 1-1	**Supporting Information 2-1**	**Supporting Information 3-1**
85% of plague cases are transmitted from rodents, also known as bubonic plague, which does not spread from human to human.	A person is only infectious for about 1-3 days.	The US reports approximately 25 cases of plague a year. There has not been a sustained outbreak for nearly a century.
Supporting Information 1-2	**Supporting Information 2-2**	**Supporting Information 3-2**
Pneumonic plague spread from person to person usually occurs after long periods of close contact such as care givers or medical professionals.	A person becomes ill very rapidly and it would be difficult to travel while experiencing symptoms.	A disease with such a low infectious rate cannot sustain an US-wide outbreak.
Supporting Information 1-3	**Supporting Information 2-3**	**Supporting Information 3-3**
A person is not infectious without symptoms.	An ill person from pneumonic plague would be easier to spot than other diseases due to the rapid progression and severity of the disease.	Previous large numbers of deaths due to plague were due to unsanitary conditions, lack of modern medicine and antibiotics, and large numbers of rodents.

In the event of a pneumonic plague outbreak, it is also important to state what is unknown as it is important to state what is known. Public health officials and government officials maintain credibility when they explain what factors are still unknown instead of

guessing on what the public may want to hear. More panic may be created if a wrong message is conveyed. Instead of creating calm, officials may create more panic if they accidentally convey the wrong message. Even if officials present new and accurate information later, their credibility could have been destroyed by not being previously honest about the unknowns. Therefore, it is best to state "we don't know;" as an educated guess may backfire in the long run. An untrue statement will become a roadblock to any future truthful or useful statements. The effectiveness of any message will diminish. If a pneumonic plague outbreak occurs, it is imperative to inform the public of the outbreak's origins especially since the world has not seen a serious outbreak of pneumonic plague in over a century. Officials must explain to the public how this modern outbreak differs from the epidemics of the Middle Ages. It is vital to outline the differences in the population, the sanitary conditions, and the medical treatments.

Furthermore, it is also important that officials advise the public when further information will be available, how those messages will be presented, and when official social media and websites will be updated. The public will look for new information if told when and where to find the most-up-to-date information. However, it is key not to give false hope or guarantee victory unless a victory is 100% guaranteed. If the source of the disease has been contained and the secondary infections isolated, then the public can be reassured.

Inaccurate information and promises broken early may worsen a crisis. The public will lose all trust in the officials if early in a crisis the officials are wrong. The public may turn to anyone who appears to be right even though those individuals are unqualified.

Public officials need to establish their expertise and credibility as soon as possible. Those officials need to be visible and known before a crisis begins with an established a pattern of credibility.

3) Empower the public

The public must be shown how their actions will help prevent the spread of disease. Educational programs should include: coughing into an elbow during an aircraft flight, the use of hand sanitizer before embarking an aircraft and right after disembarking, and presenting a list of troubling symptoms that require a visit to the hospital. The public can be educated that they have the power to stop the disease. If officials lead by example, it may create a natural habit pattern. When actions of trusted individuals mirror the health guidelines, the public will be more accepting of the underlining message. Studies have shown that if the public can take actions during a crisis it can help restore a sense of control and overcome feelings of hopelessness and helplessness.[358]

Different media outlets should disseminate the same messages to accommodate the various generational, political, and social differences in the population. Officials should take advantage of the various television and radio news channels, public announcements during entertainment programs, as well as the multitude of social media outlets and websites. Despite the differences in media markets, all should broadcast the same consistent message. National and local leaders, including educators and religious officials, can also disseminate simple preventative and basic infection control measures. For example, teachers can remind students to wash their hands before lunch periods.

[358] Center for Disease Control and Prevention. (2014). Crisis and Emergency Risk Communication.

These simple messages will have a lasting impact, reduce stress, and ultimately lessen disease spread.

Communication is the key when there has been an attack and the media should be used as an ally. As terrorists use the media and the threat of panic to disseminate their cause; the media can also be used as a tool to educate the public on actual threats, possible exposures, and personal health implications. With daily press releases, frequent media interviews, and updated websites, the majority of the public may feel properly reassured. Education and media used for accurate and timely information will ensure that knowledgeable emergency responders and the general public will react in a proper manner ultimately mitigating the disaster from an aviation-based biological attack. As an attack of unknown biological nature has profound psychological impact, communication is essential to minimize the feeling of helplessness. Officials must educate the public on the true medical threats that come with exposure and of the risk of disease if an individual was at or near the airport during an attack using *Y. pestis*. However, variables and factors concerning a natural outbreak of pneumonic plague are the same for a bioterrorist attack using *Y. pestis*. The preparation for one becomes dual-use for the other. Emergency response officials need to provide consistent, accurate, and simple information that can help the public determine their actual risk of exposure and disease, detect symptoms, and seek treatment.

Recommendation #8: Wide-spread vector termination (Audience: airports and affected cities)

Studies have indicated that the sustained plague outbreaks of the past were largely due to unsanitary conditions and the prevalence of rats as a vector for the *Y. pestis*

pathogen. The latest outbreak in Surat was mainly due to the proliferation of the rat population and the unsanitary conditions of the city. Without a significant rat population to vector the disease, it is doubtful that a modern day plague outbreak can occur especially in an industrialized nation. Though the attack using *Y. pestis* will be easily disinfected because of the fragile nature of the pathogen, it is possible that it may infect a random rodent and replicate if the rodent population is substantial. If the attack happened in New York City, there is a possibility that panic may spread as individuals equate plague and rats. Responsive public health measures may seek to kill these vectors which will also help in improving the sanitary conditions of the city. The act of cleaning the airport and eliminating vectors will also aid in reducing the panic. It shows the measures that the country is willing to take to protect its citizens while keeping them informed of the risks. Assurances from public health personnel and taking the lead by example will minimize the threat and teach the public the difference between a current threat of plague and ones from the distant past.

Discussion

In using pneumonic plague as a scenario to determine if aircraft spread a disease as a role of an incubator with in-flight transmissions, the answer is minimally. The airport itself is more of an incubator of diseases as individuals wait in the same ticketing lines, gates, and jet ways with possible infected passengers with diseases that transmit from person to person. The recommendations presented account for passengers who are near the vicinity of infected individuals at the airport and not just traveling on an aircraft. Historical examples and models show that the spread of SARS and H1N1 are

significantly affected by air travel. Due to the advancements in travel technology and engineering, humans reach any part of the globe within the incubation time of most diseases allowing travelers to unintentionally carry a disease from coast to coast or from continent to continent. Ebola and pneumonic plague have short life expectancies with a high probability of death so the risk of transmission is low and the outbreak is not sustainable without further incubators. However, all public health professionals should be prepared to deal with a disease that may not be endemic to an area. The use of aircraft as a vector now shows that all areas of the Earth are susceptible to all types of diseases. In each of the recommendations, the component of public education is the utmost of importance. The scientific and medical advancements of disease prevention and treatments have diminished many infectious diseases including pneumonic plague as serious biological threat. However, pneumonic plague remains a serious psychological threat. Therefore, public health officials need to dedicate resources to creating a communication strategy and standard operating procedures as to reduce the psychological fallout from an attack or outbreak.

A bioterrorist attack that includes an aerosol transmission of *Y. pestis* will cause primary pneumonic plague associated with a high fatality rate. Subsequent person to person transmission could spread the disease across the nation. Symptoms of pneumonic plague caused by a bioweapon would resemble those of other severe respiratory illnesses. Unfortunately, early diagnosis of plague requires a large amount of suspicion, which authorities and medical personnel may not have in non-endemic areas. Basic methods to control person to person spread of the infection include hand washing, the use of masks,

gloves, and gowns, and isolation and quarantine of cases. It is important to diagnose pneumonic plague early to rapidly institute interventions and treatment, especially in the event of a bioterrorist attack. The primary cause and initial cases must be contained.

The threat of pneumonic plague is not from the disease, but from the potential psychological impact. To contain the outbreak of pneumonic plague, aviation and public health authorities should establish preventative infectious disease measures at airports, streamline contact procedures for ticketed passengers, expand the definition of "close contact," and conduct widespread educational programs. The measures will put in place a foundation for containing any infectious disease and ensure that a pneumonic plague outbreak, from a natural cause or a bioterrorist attack, cannot be sustained. Preventative public health measures, communication, and education will diminish the spread of disease and ensure that a pneumonic plague case does not cause another "Black Death."

Future areas for research

Significant questions remain to determine how to best implement preventative disease measures to mitigate disease spread from the expected seasonal flu or the unexpected exotic disease outbreak. Each disease must be modeled and interventions should be tailored. Though basic measures may impact overall global travel health, there will be times to make pointed and unique countermeasures. Further research is necessary to tailor risk factors and recommendations based on individual diseases and the path of the diseased traveler. However, countermeasures must also be weighed against potential legal and privacy issues.

Further modeling is needed to determine the economic impact of travel mitigations and determine which disease cases (if any) warrant travel restrictions. Future areas of research include modeling emerging diseases that have a high basic reproductive ratio and may cause the next pandemic such as smallpox and tuberculosis. These diseases may become a threat as another viable bioterrorist agent. Further models and interventions may need to account for any future intelligence that may indicate efforts into genetic mutations to increase the transmissibility of a disease.

Additional research is essential on understanding individual's attitudes toward travel health habits and the generational differences that may require different preventive measures. Various travel scenarios need to be studied to determine scenarios that infected patients may encounter that would lead to higher risk factors of disease transmissions. Further, business case analyses are required to determine best ways to incentivize individuals from travelling with an illness. Global health, in relation to air travel, is a continuously evolving field that requires up-to-date evidence based research for scientifically and economically sound advice that may limit a global pandemic.

APPENDIX

Full Disease Parameter Results Table

The diseases in yellow are default parameters in road and population characteristics within the STEM model. All other disease parameters are based on researched scientific evidence and calculated values.

Table 11 Full Disease Parameters Results Table

SEIR Model	SARS	H1N1	Ebola	Plague
Time Period	86400000	86400000	86400000	86400000
Reference Pop Density	100	100	100	100
Road Proportion	0.01	0.01	0.01	0.01
Char Mixing Distance	2.25	2.25	2.25	2.25
Non-Linearity Coefficient	1	1	1	1
R_o	2.5	2.45	1.75	1.3
Infectious Time	21	10	15	2
Incubation Period	7	4	10	3
Transmission Rate (β)	0.119047619	0.245	0.116666667	0.65
Inf Recovery Rate (ϒ)	0.047619048	0.1	0.066666667	0.5
Inf Mortality Rate (μi)	0.013333333	0.00016	0.046666667	0.495
Immunity Loss Rate (σ)	0.0027	0.0027	0.0027	0.0027
Incubation Rate (e)	0.142857143	0.25	0.1	0.333333333
Case Fatality Rate	0.28	0.0016	0.7	0.99

Spatio-Temporal Epidemiological Modeler Data Entry Screenshots

1) SARS

2) H1N1

3) Ebola

4) Pneumonic Plague

SARS

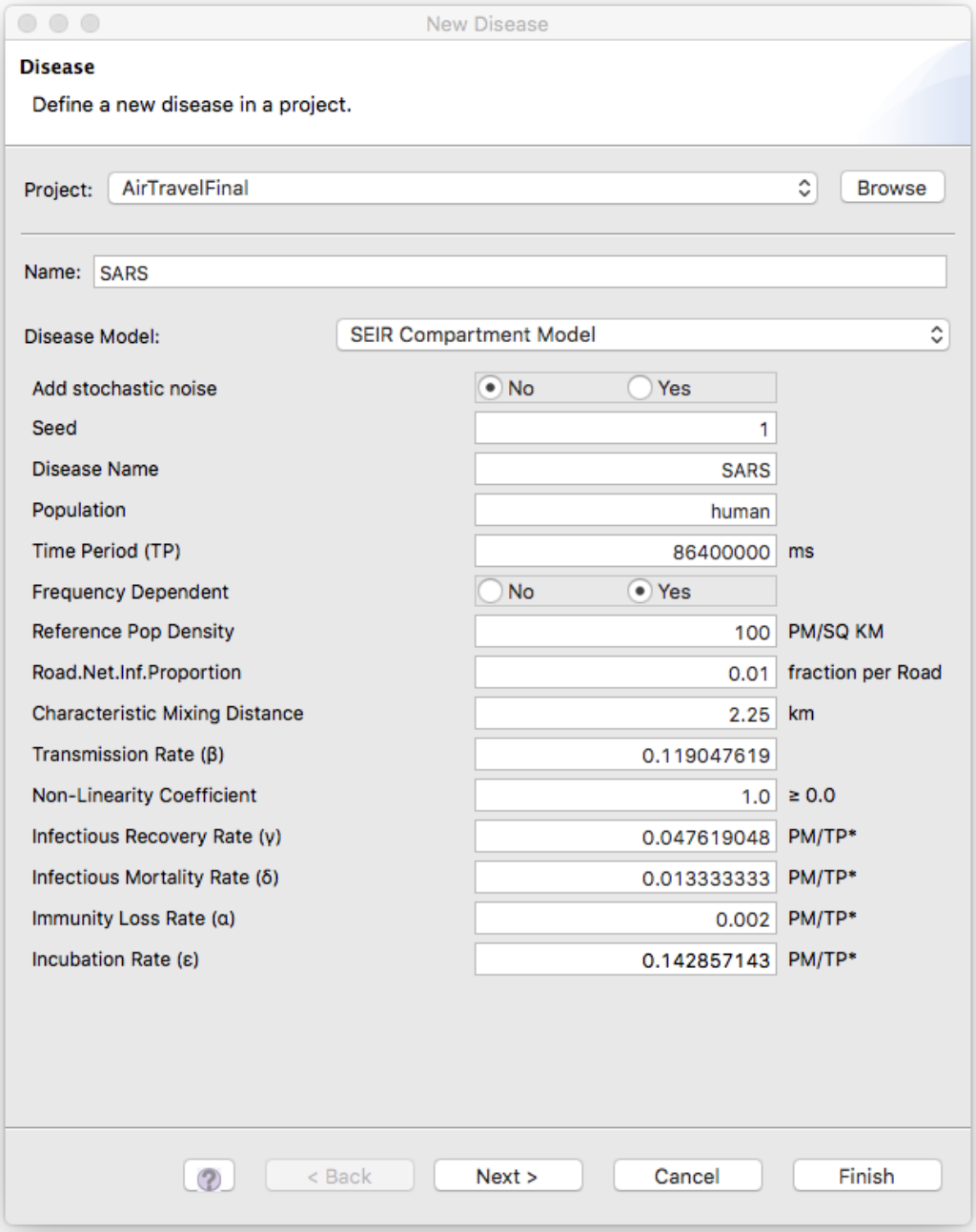


Figure 24 SARS STEM Parameters Input (Screenshot)

H1N1

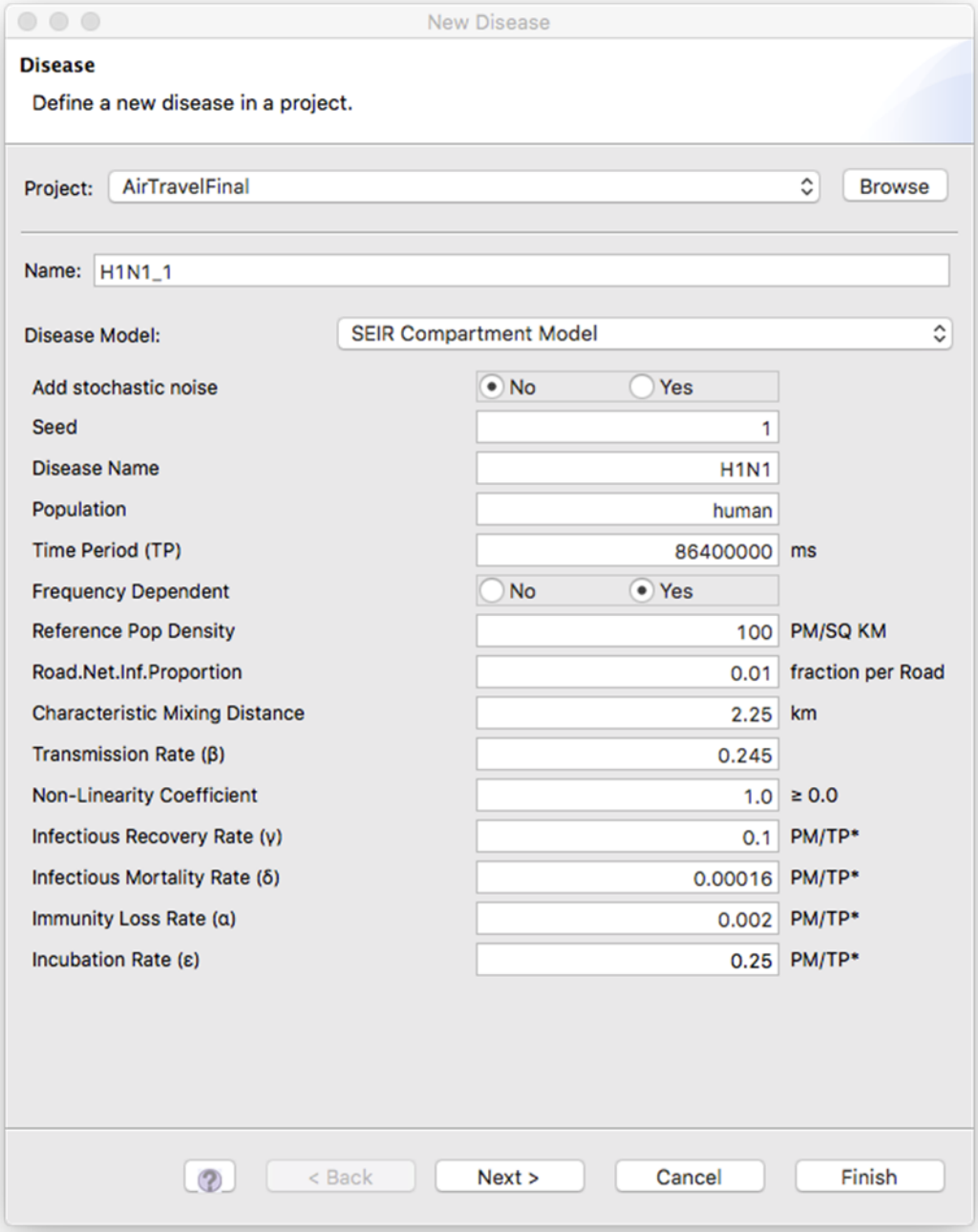


Figure 25 H1N1 STEM Parameters Input (Screenshot)

Ebola

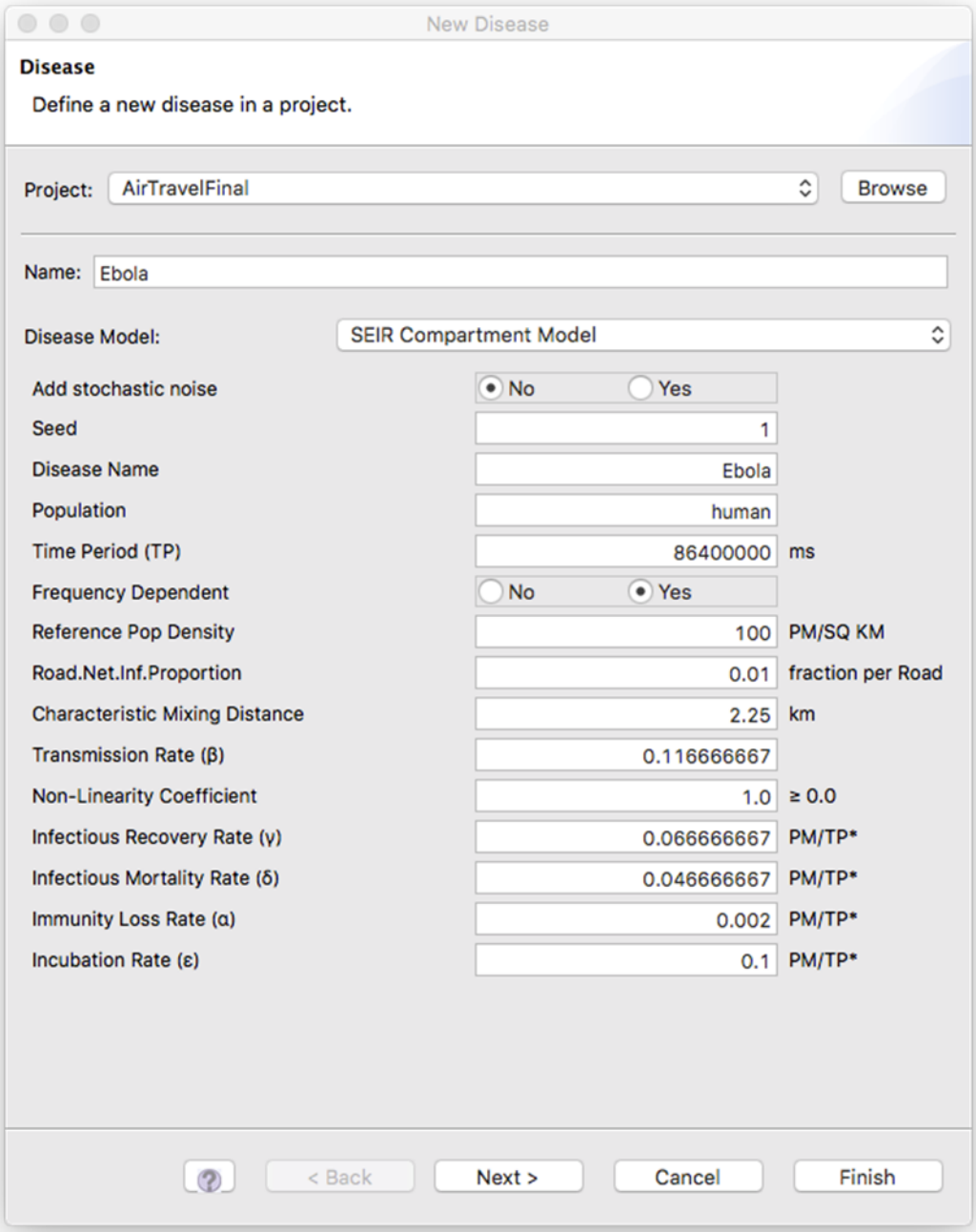


Figure 26 Ebola STEM Parameters Input (Screenshot)

Pneumonic Plague

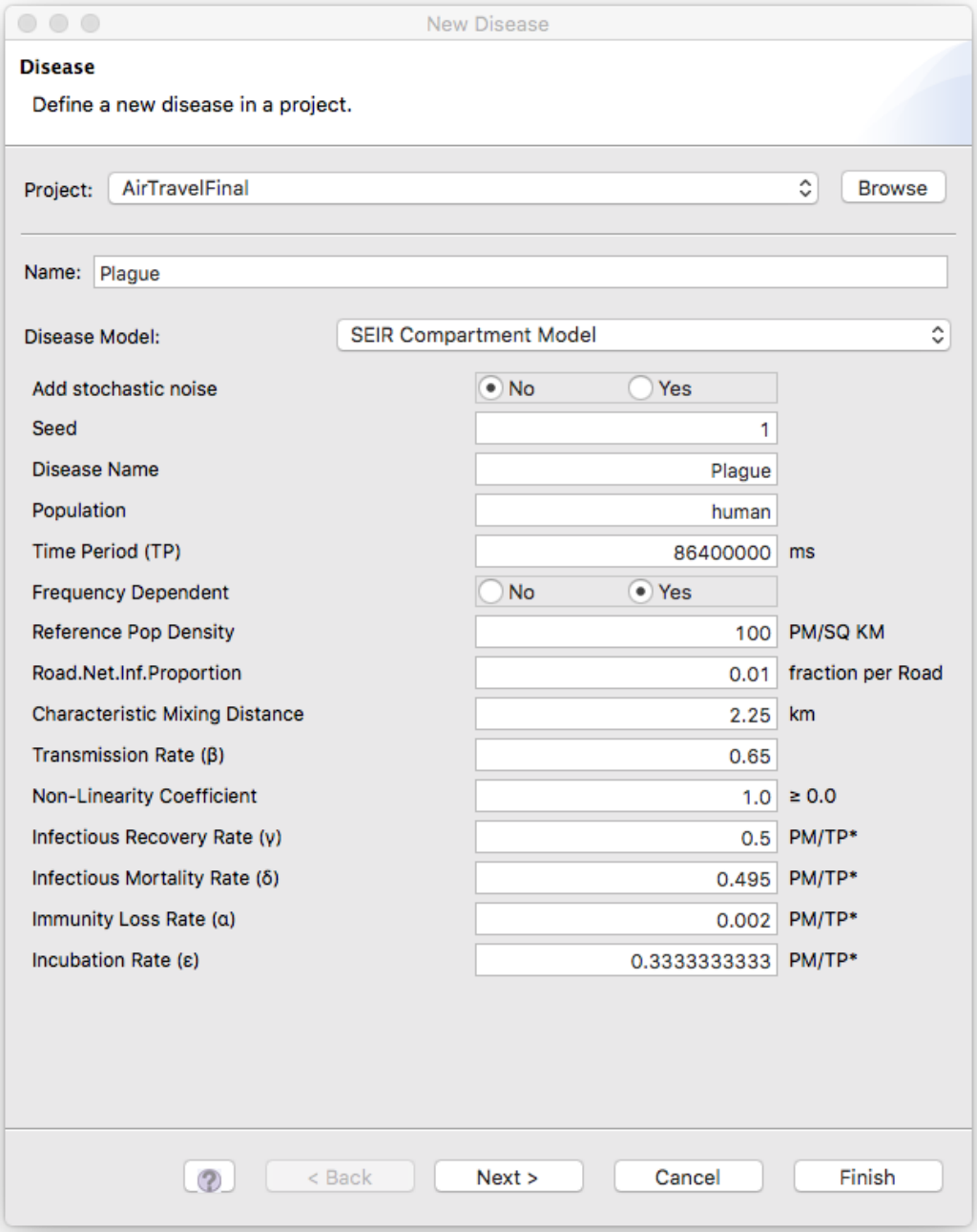


Figure 27 Pneumonic Plague STEM Parameters Input (Screenshot)

STEM Visual Depictions of Disease Infection Spread

1 Index Case: Arriving JFK International Airport, Queens, New York

1) 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

2) 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

3) 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

4) 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

5) 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

6) 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

10 Index Cases: Arriving JFK International Airport, Queens, New York

1) 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

2) 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

3) 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

4) 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

5) 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

6) 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

1 Index Case: Arriving JFK International Airport, New York

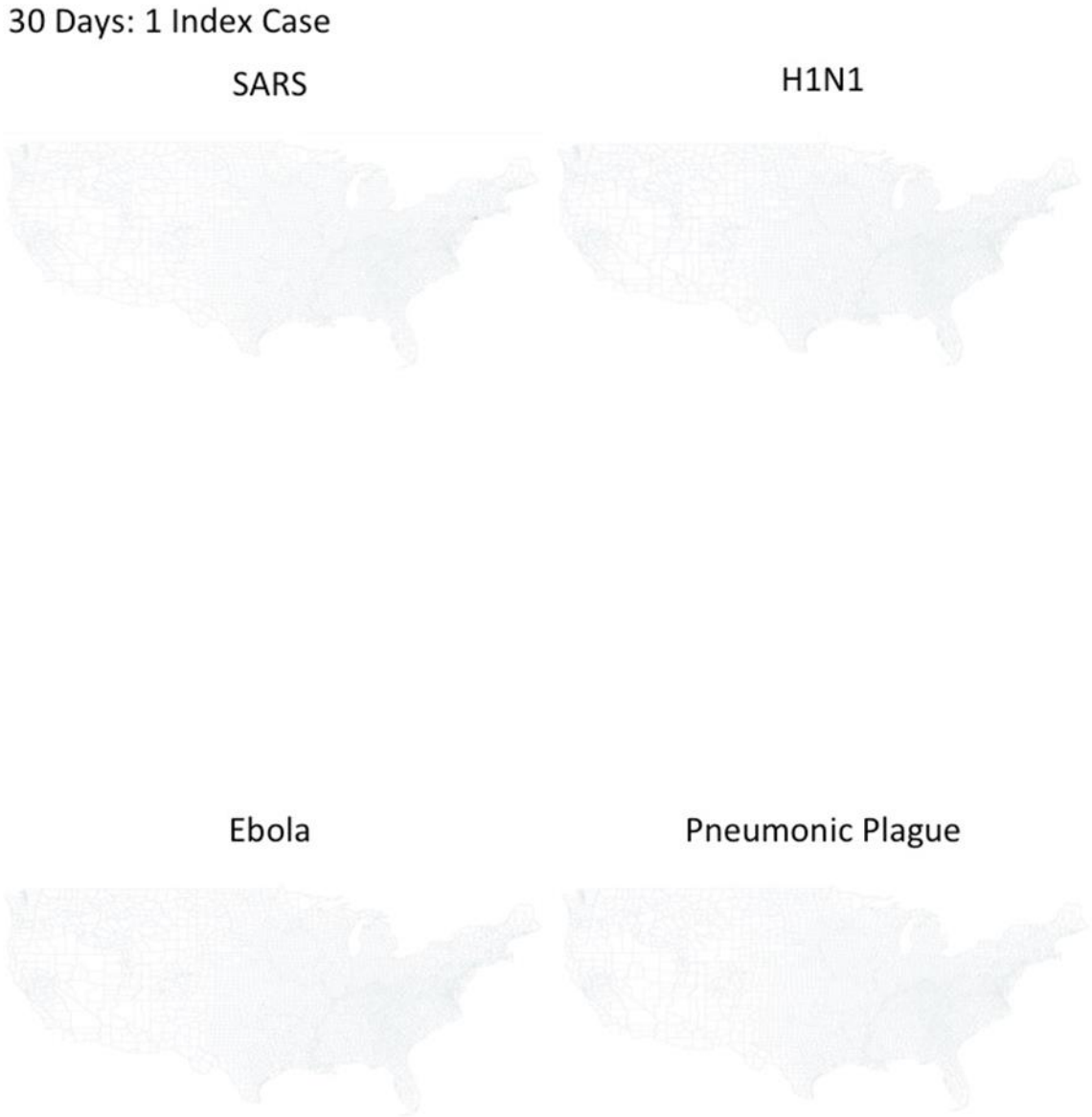


Figure 28 One Index Case: 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

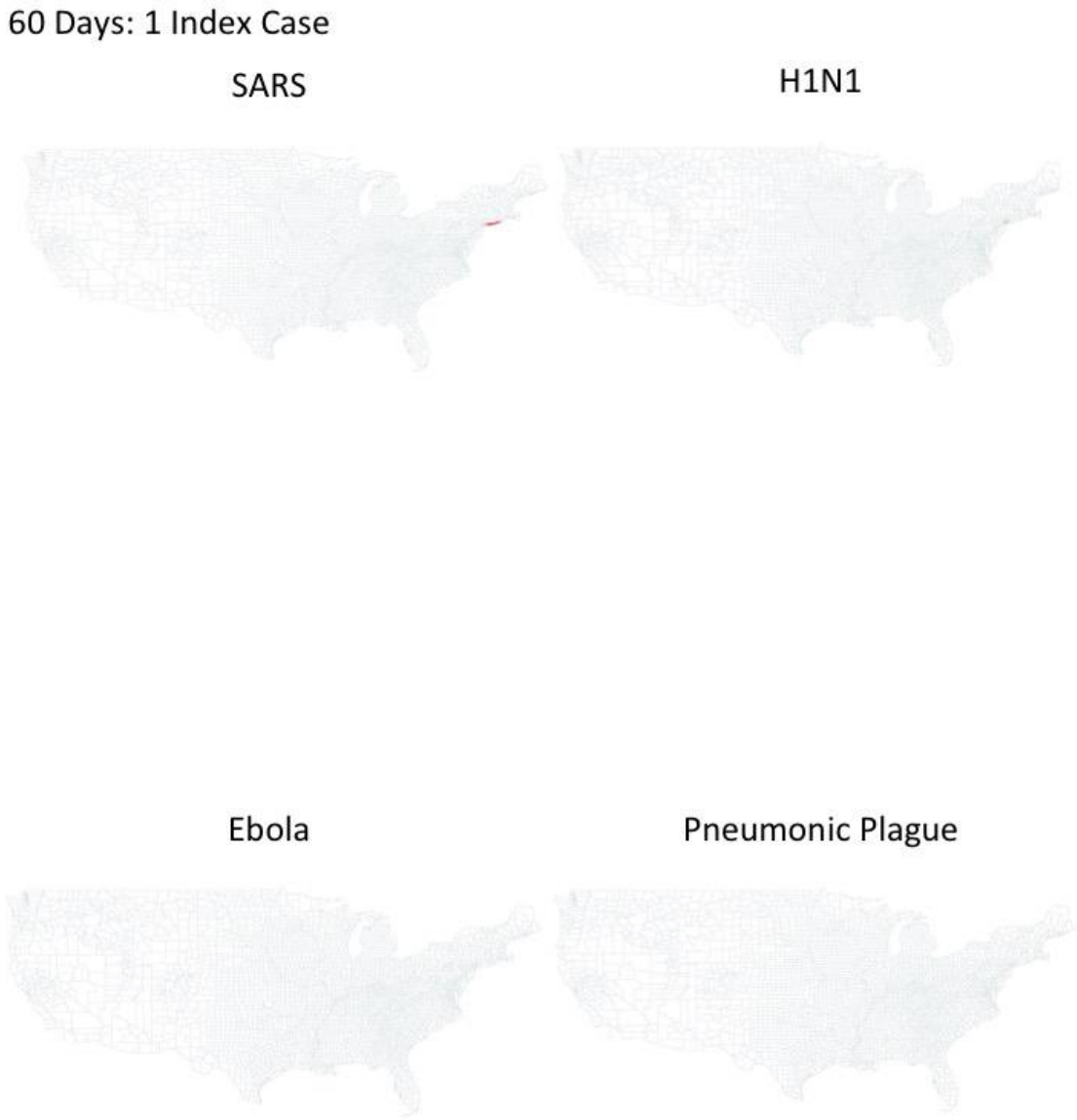


Figure 29 One Index Case: 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

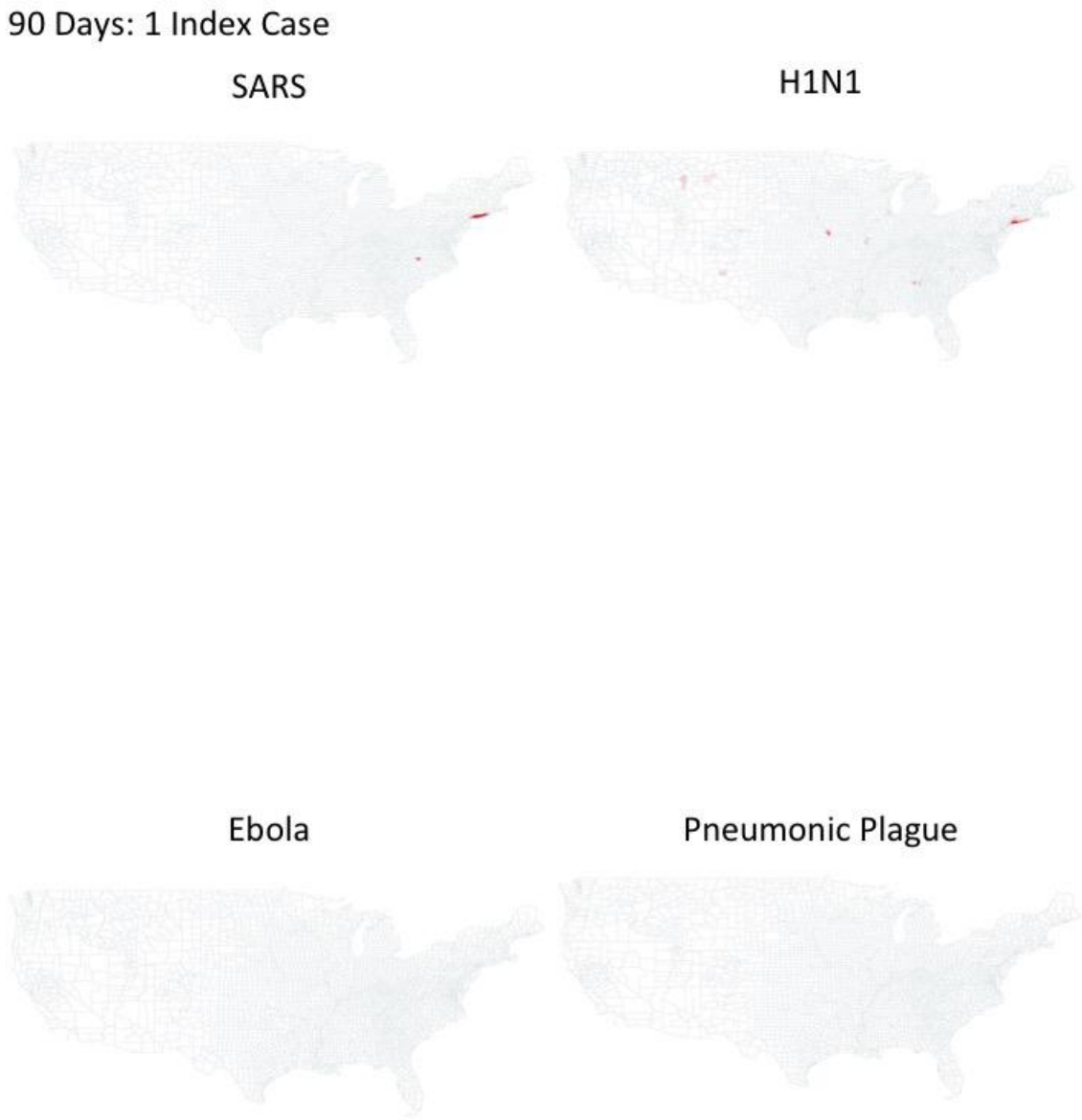


Figure 30 One Index Case: 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

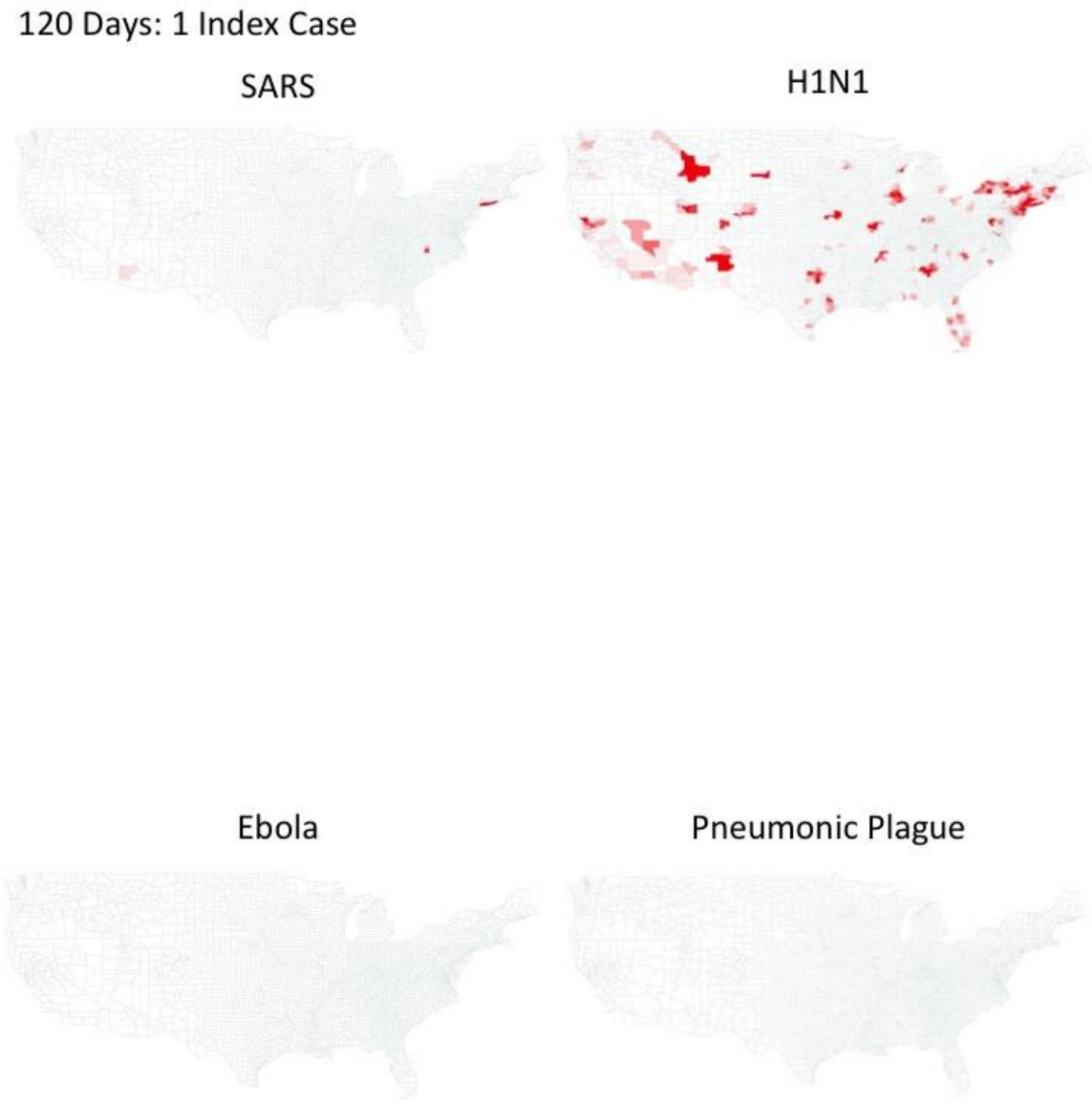


Figure 31 One Index Case: 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

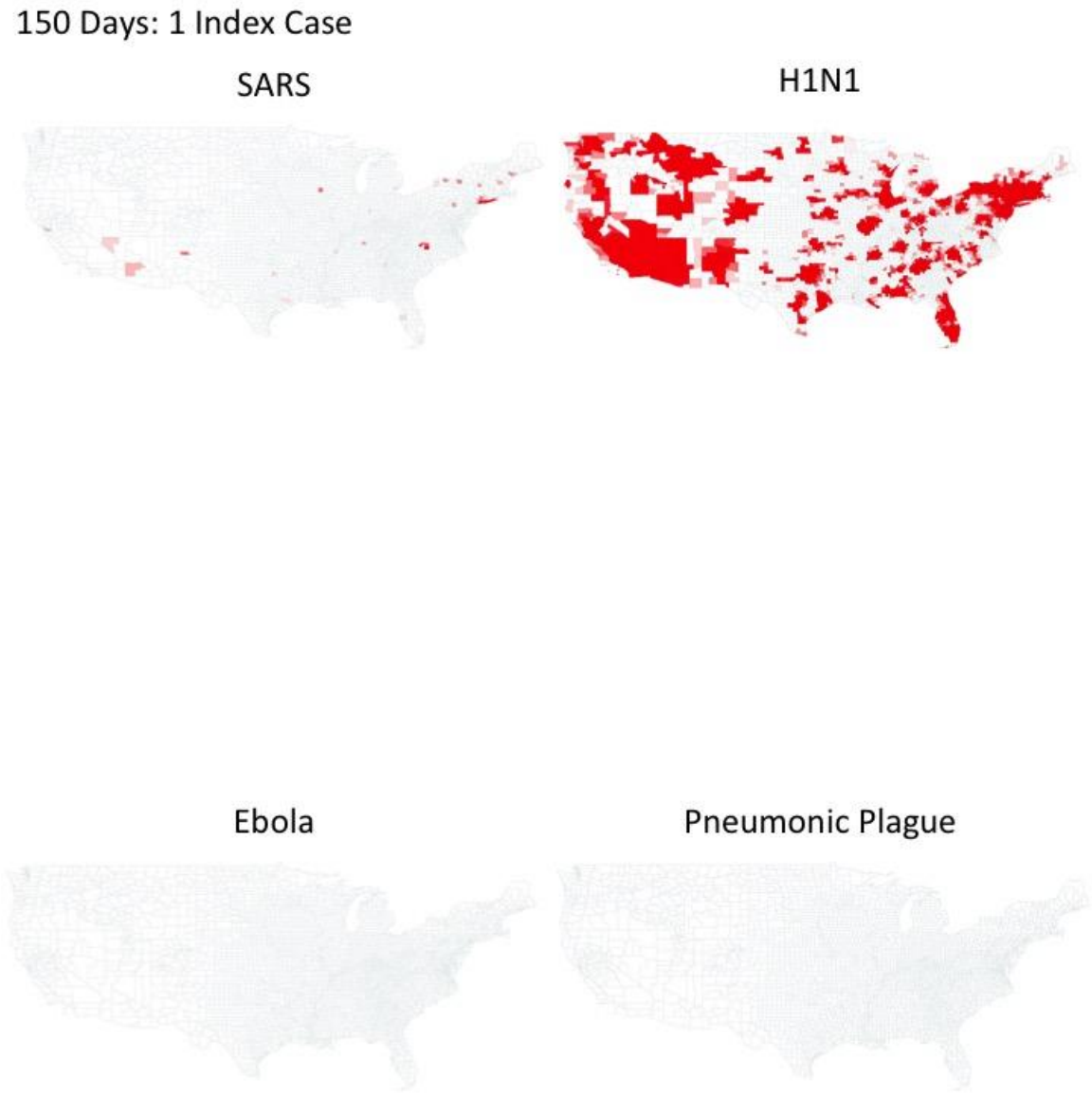


Figure 32 One Index Case: 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

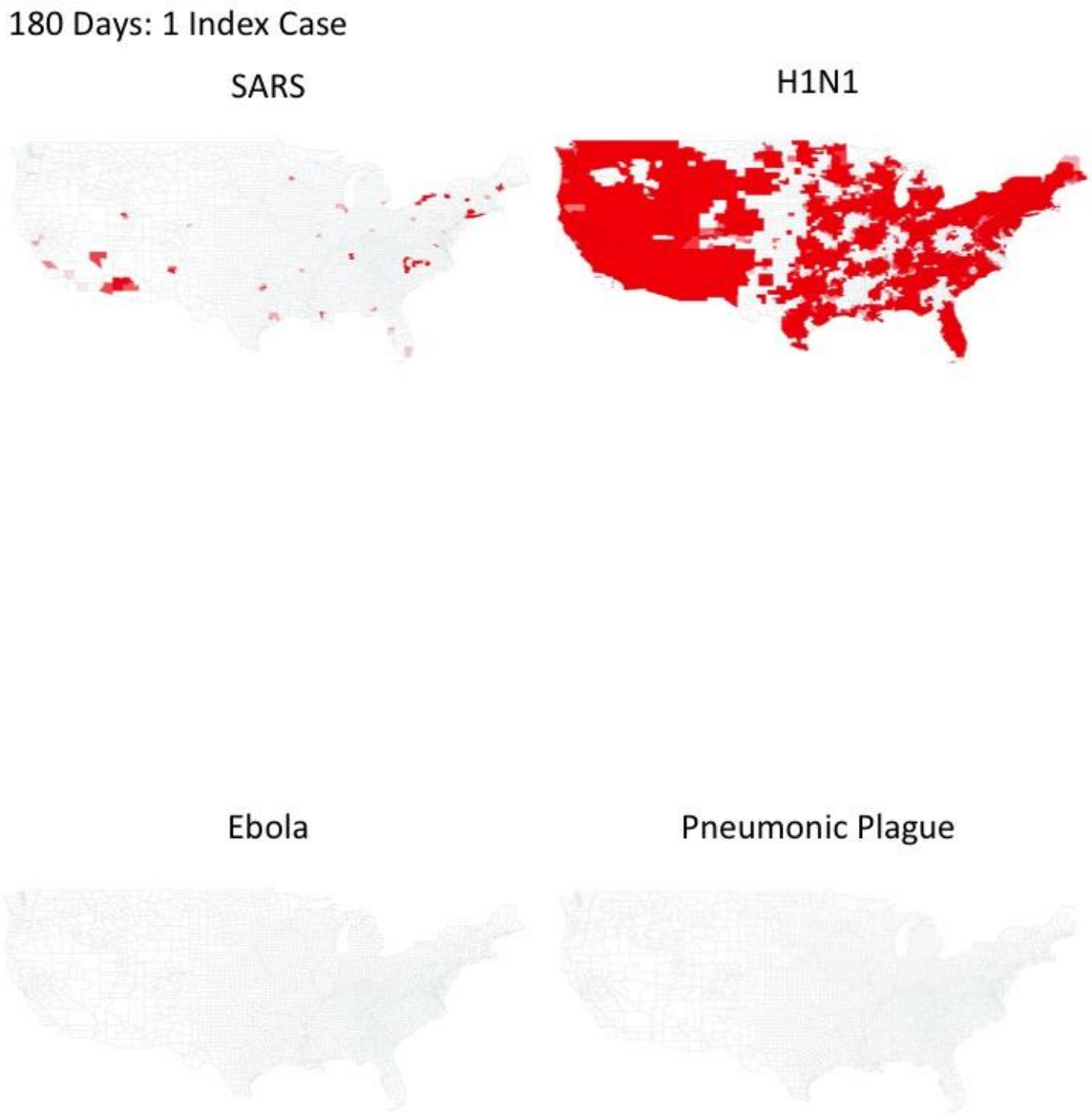


Figure 33 One Index Case: 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

10 Index Cases: Arriving JFK International Airport, New York

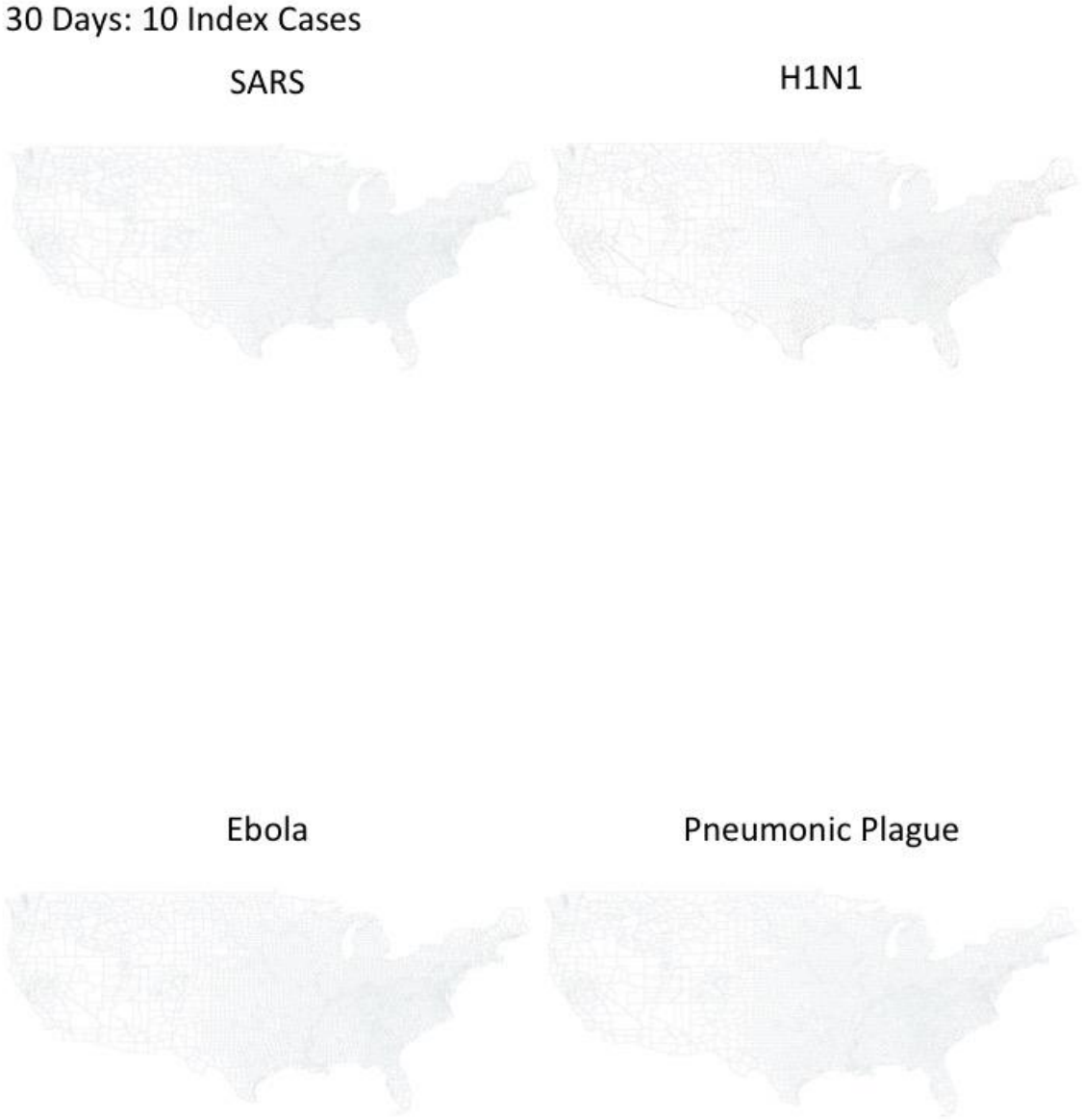


Figure 34 Ten Index Cases: 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

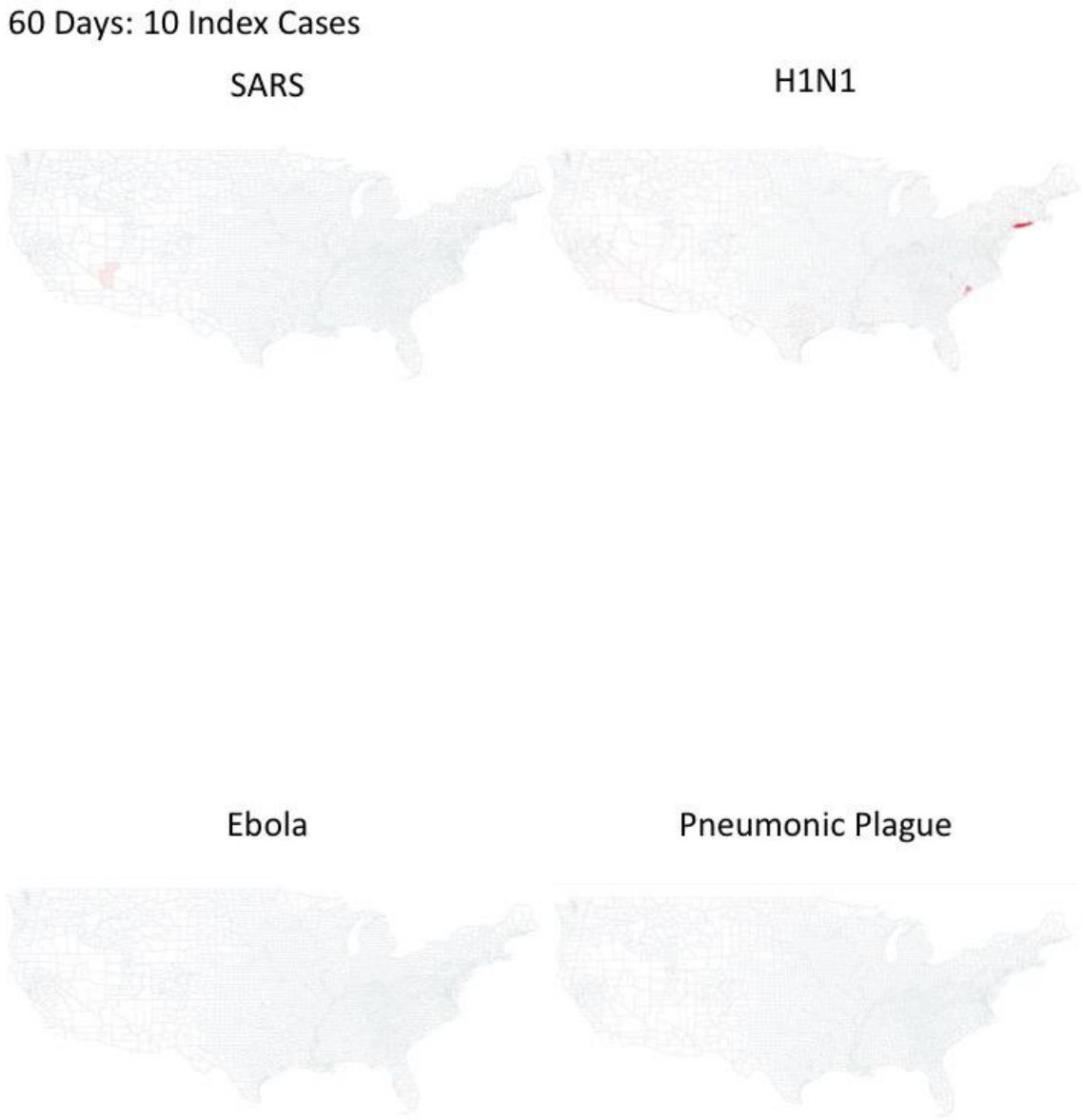


Figure 35 Ten Index Cases: 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

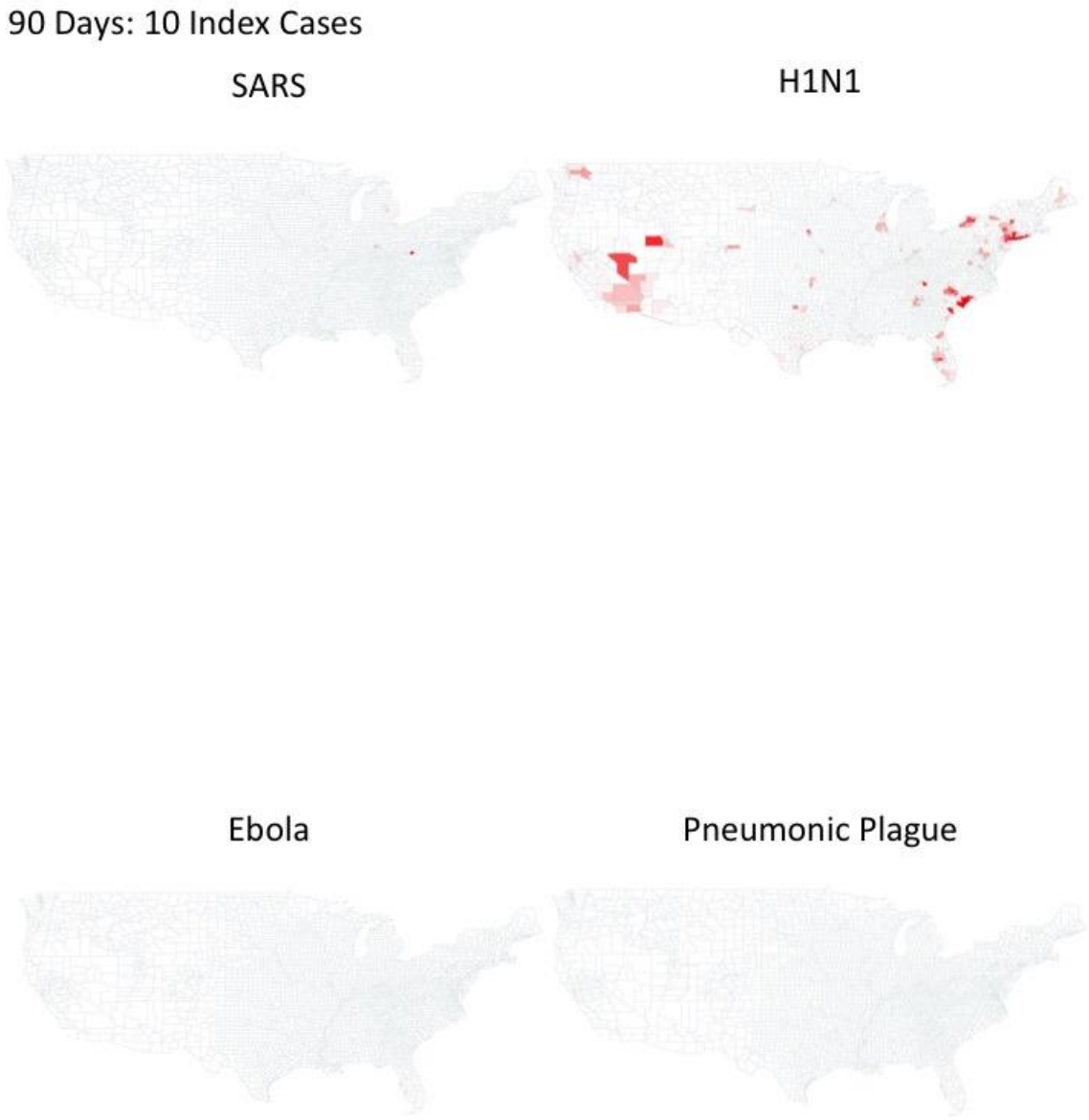


Figure 36 Ten Index Cases: 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

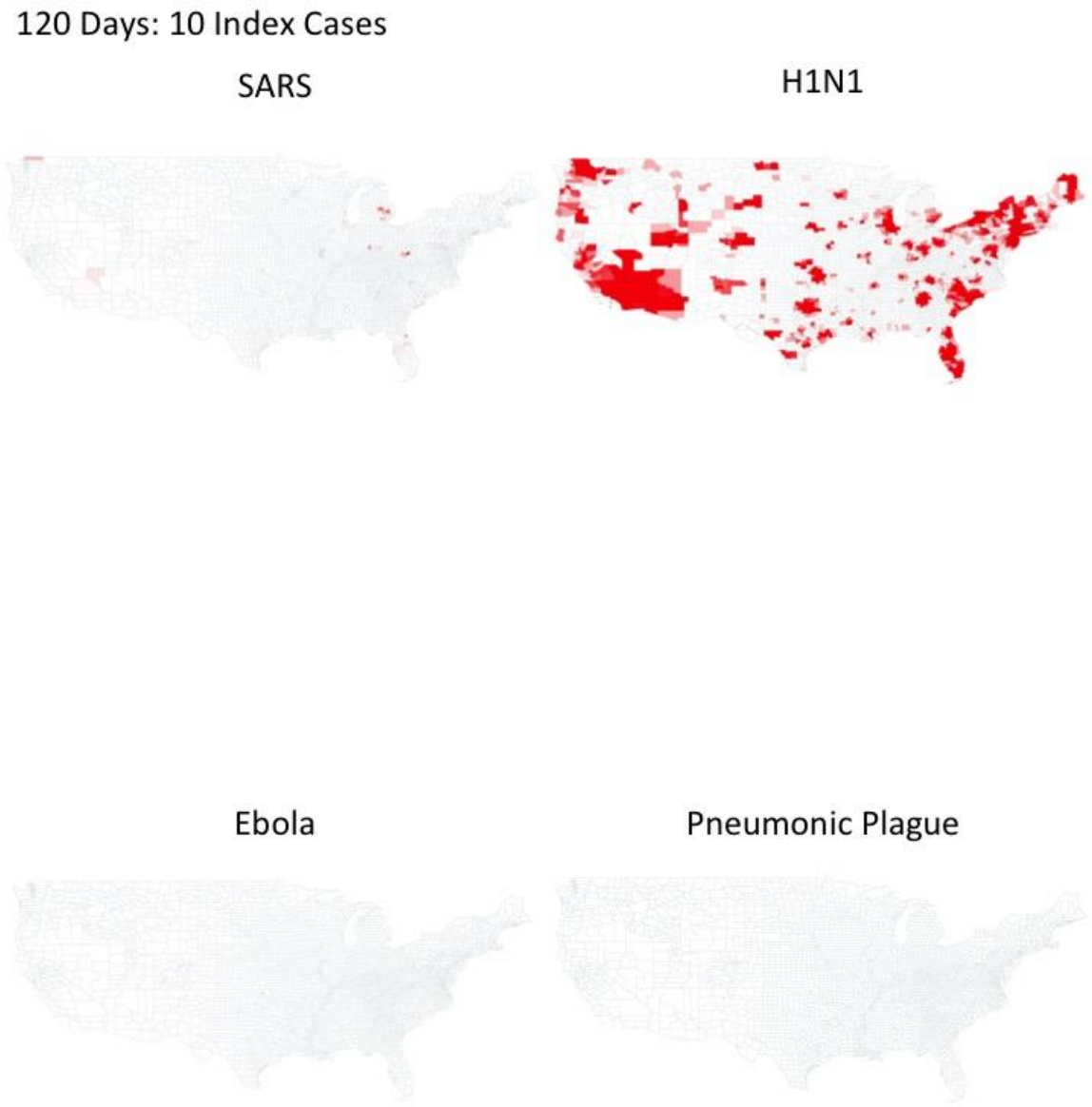


Figure 37 Ten Index Cases: 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

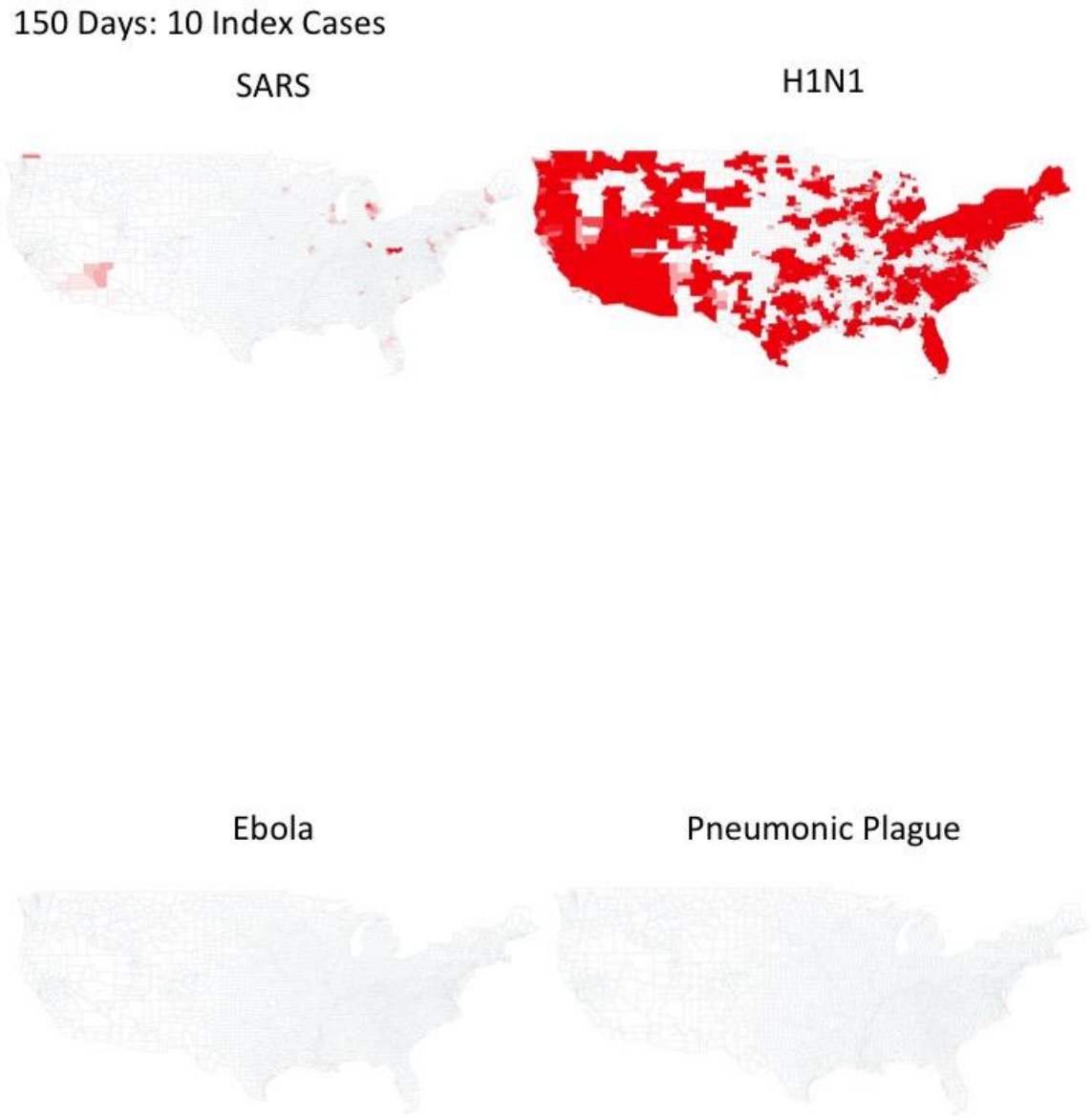


Figure 38 Ten Index Cases: 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

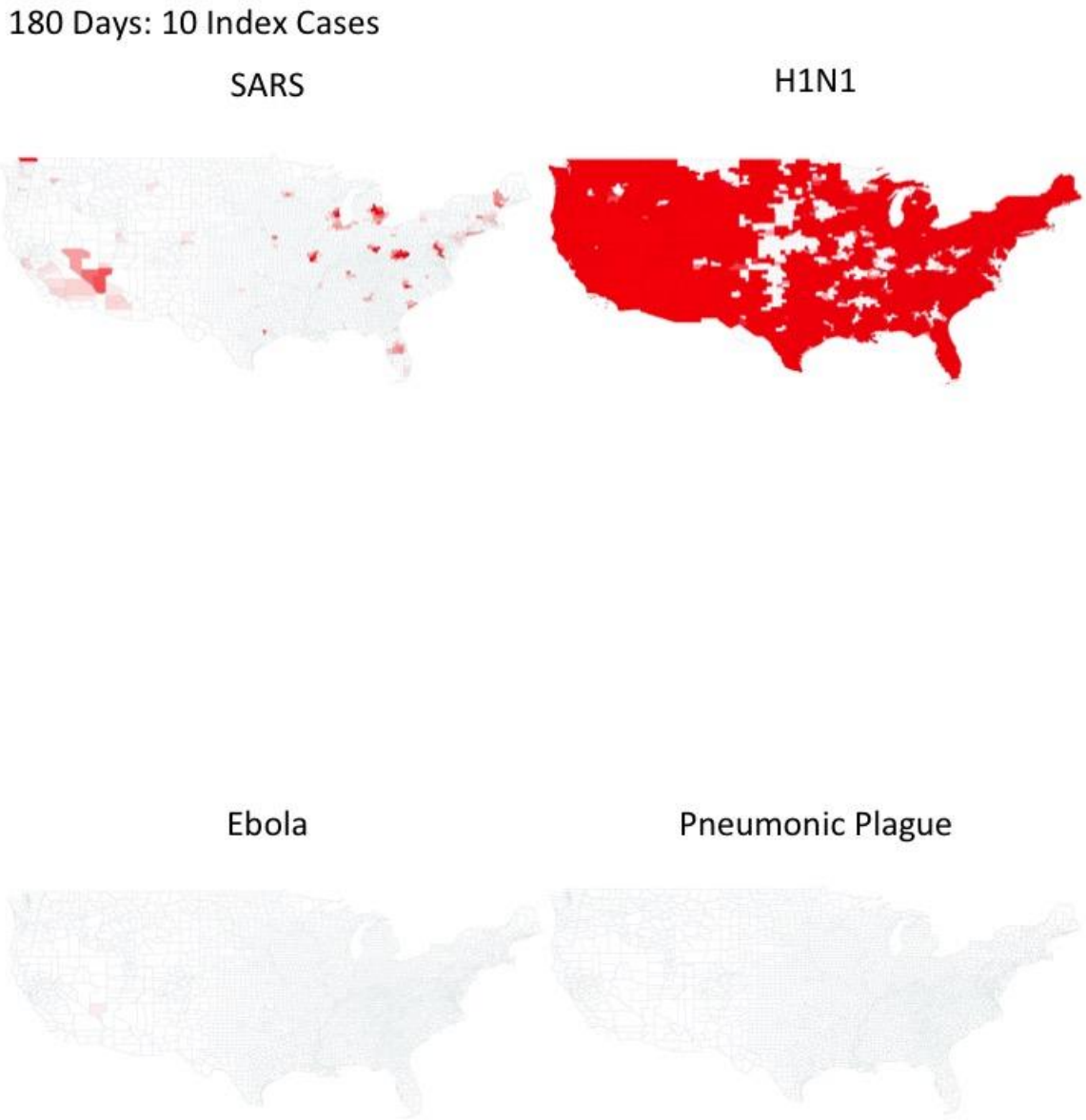


Figure 39 Ten Index Cases: 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

Comparison of Case Totals per Day per Disease per Compartment, 1 index case

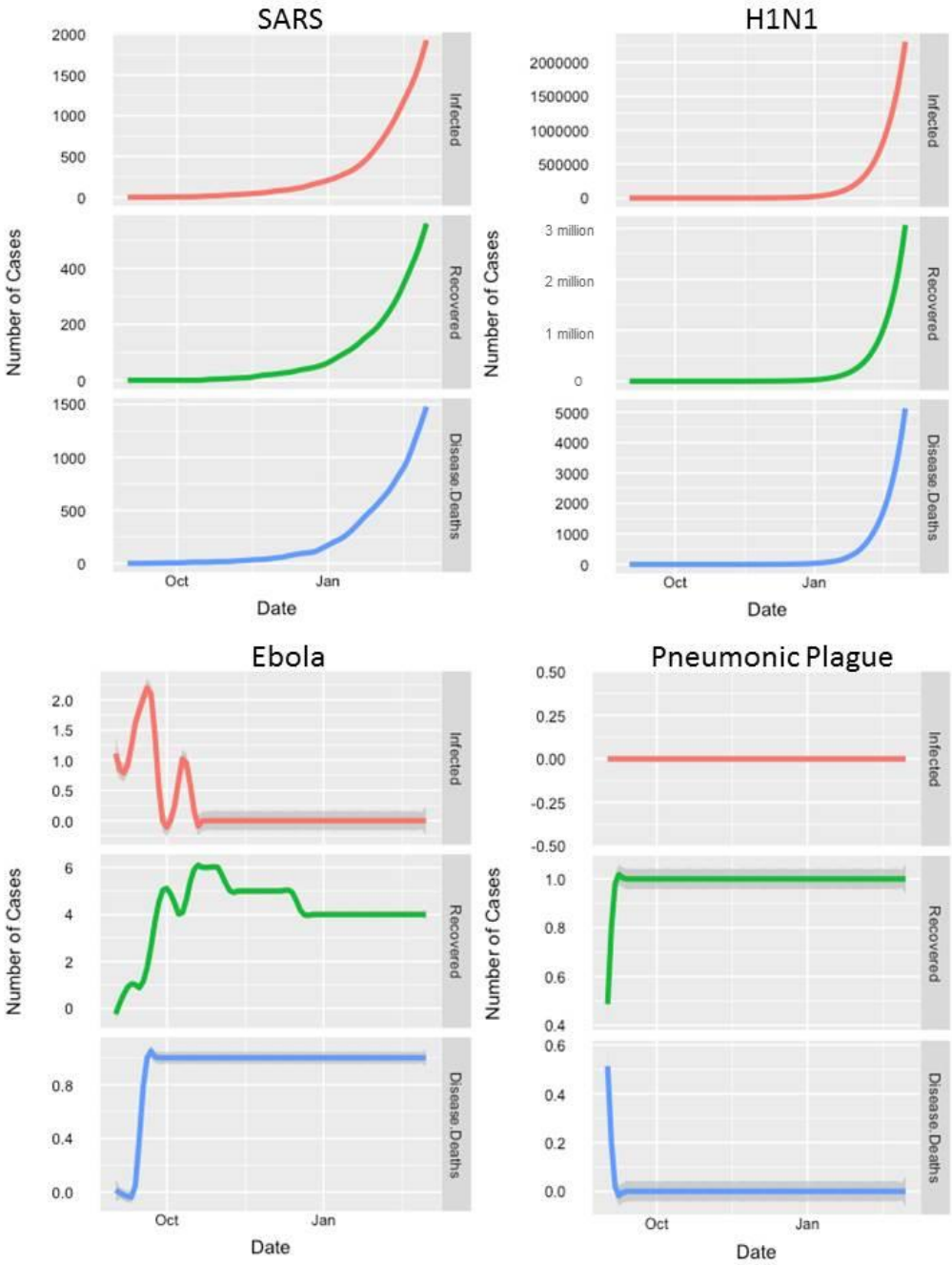


Figure 40 Comparison of Case Totals per Day per Disease per Compartment,1 index case

Comparison of Case Totals per Day per Disease per Compartment, 10 index cases

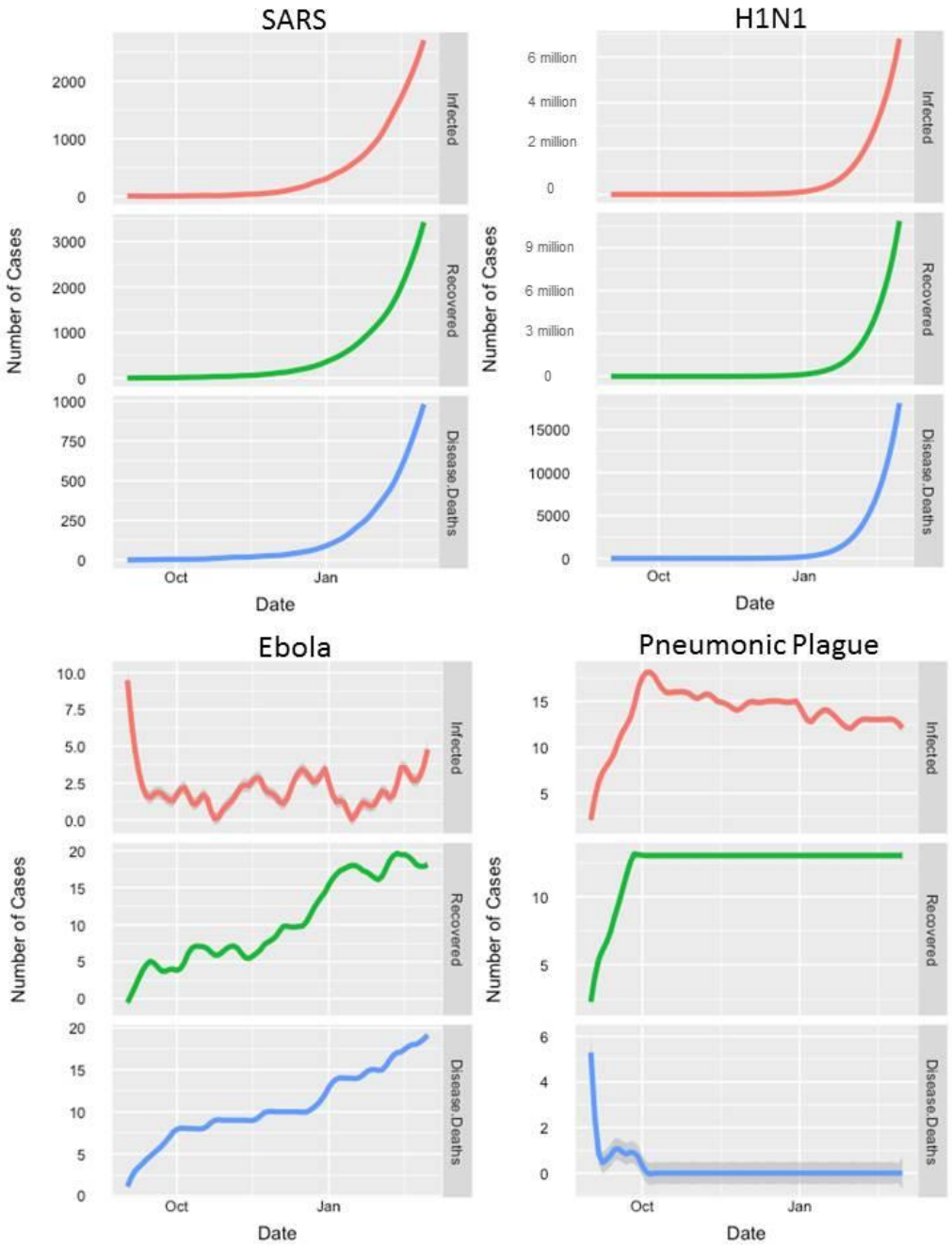


Figure 41 Comparison of Case Totals per Day per Disease per Compartment,10 index cases

Comparison of Air Travel and Non-Air Travel by Disease

1) SARS

2) H1N1

3) Ebola

4) Pneumonic Plague

SARS

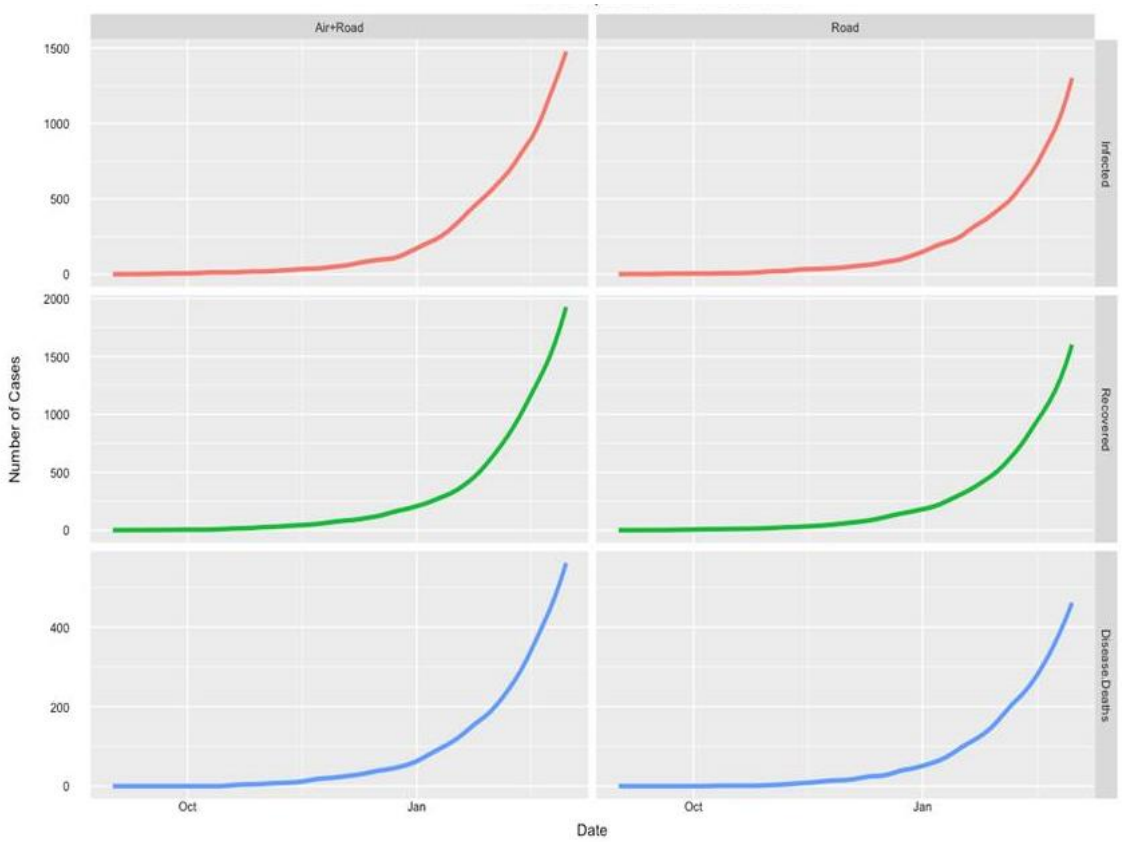


Figure 42 SARS Air Travel vs Non-Air Travel; Total Cases Per Day by Compartment

H1N1

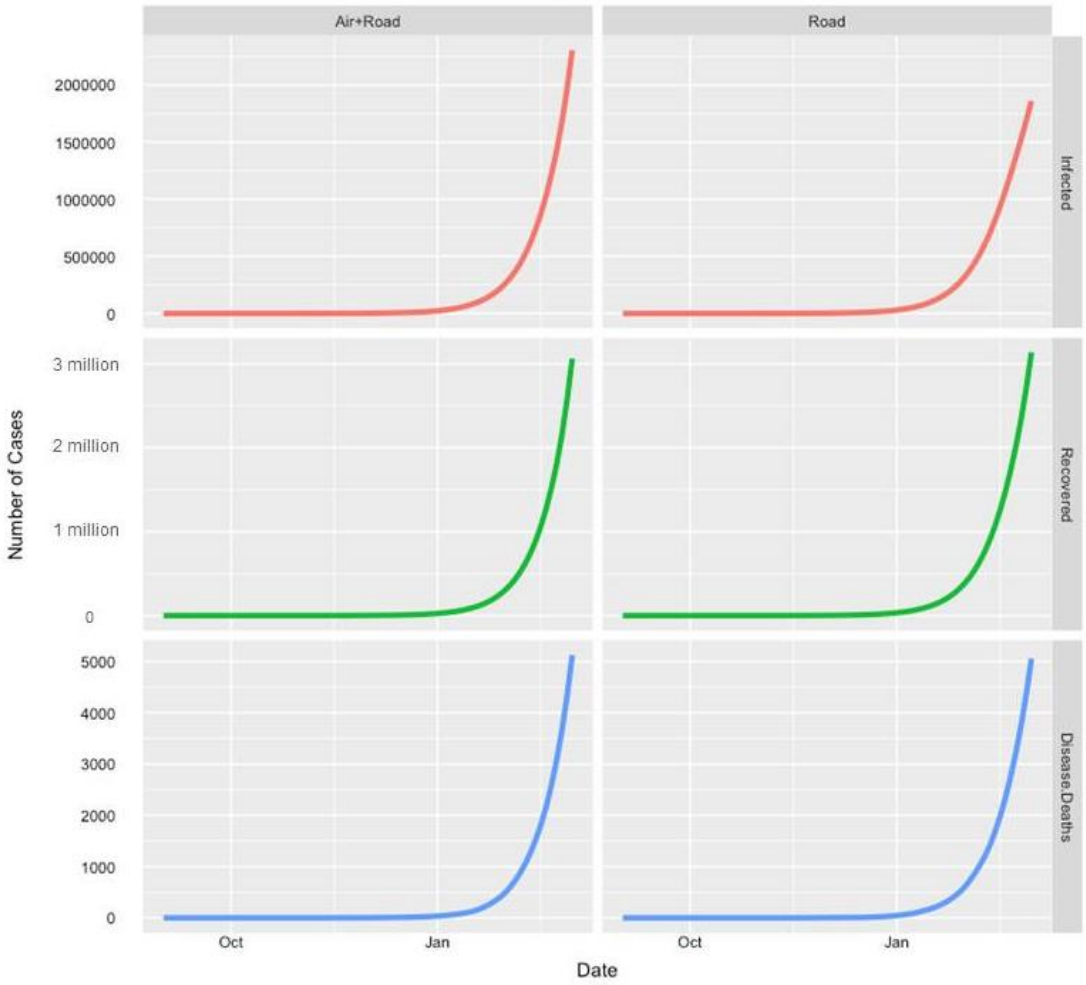


Figure 43 H1N1 Air Travel vs Non-Air Travel; Total Cases Per Day by Compartment

Ebola

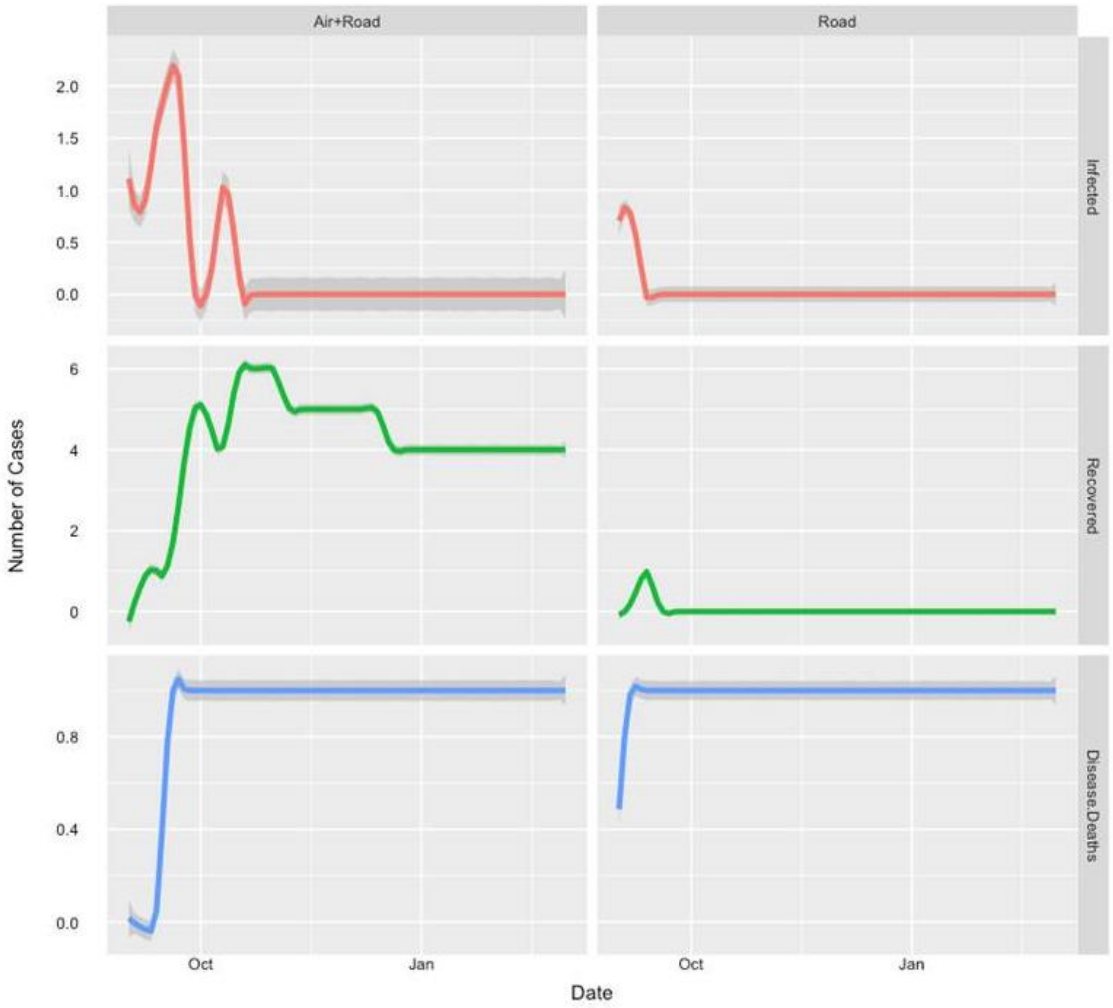
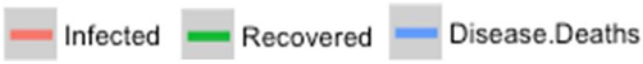


Figure 44 Ebola Air Travel vs Non-Air Travel; Total Cases Per Day by Compartment



Pneumonic Plague

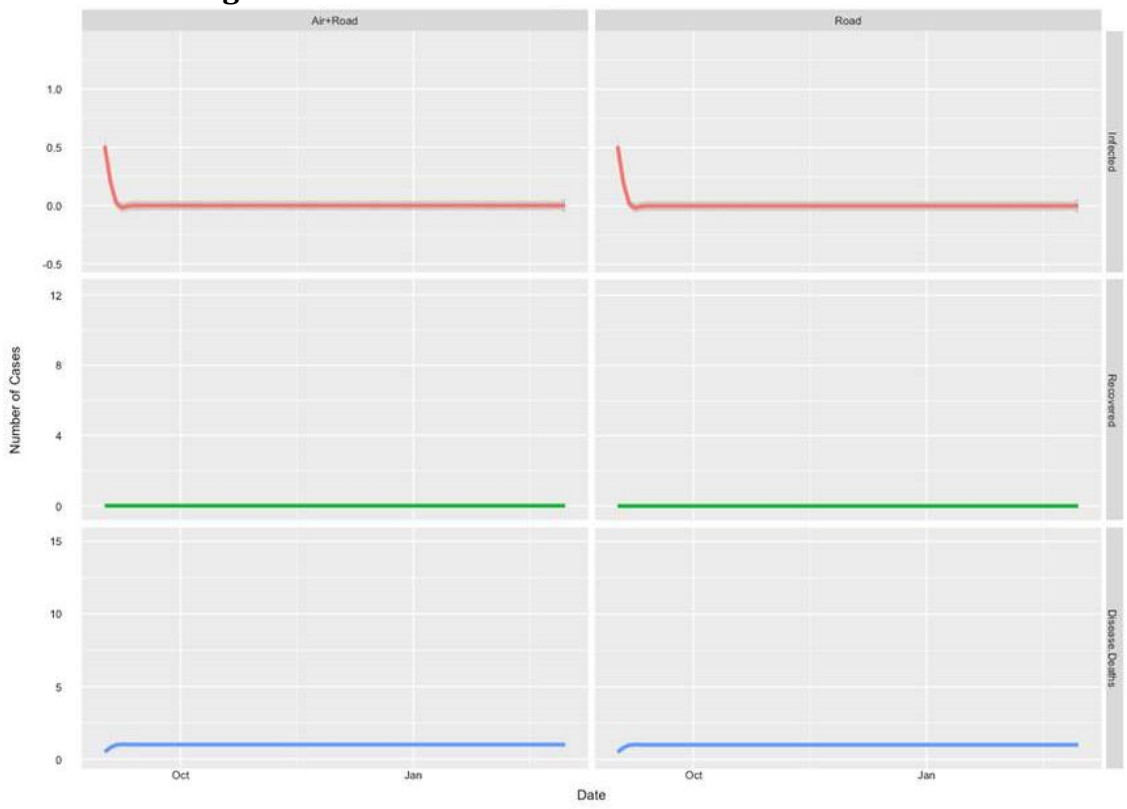
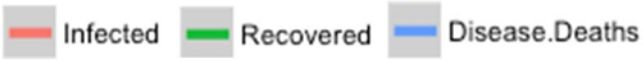


Figure 45 Pneumonic Plague Air Travel vs Non-Air Travel; Total Cases Per Day by Compartment



STEM Visual Depictions of Disease Infection Spread (Without Air Travel)

Ground Transportation: Queens, New York

1) 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

2) 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

3) 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

4) 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

5) 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

6) 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

Ground Transportation: Queens, New York

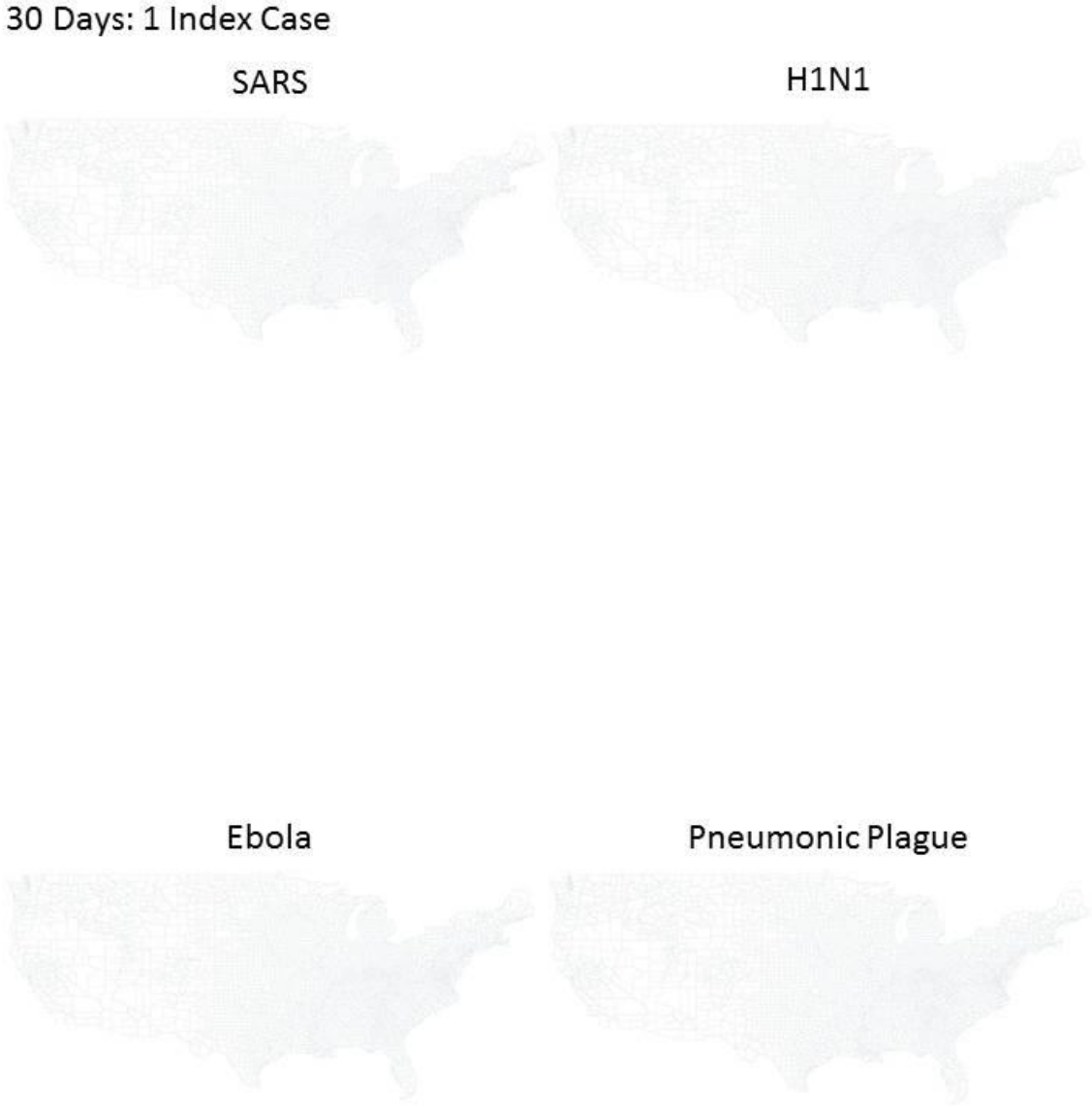


Figure 46 Ground Transportation: 30 Days (SARS, H1N1, Ebola, Pneumonic Plague)

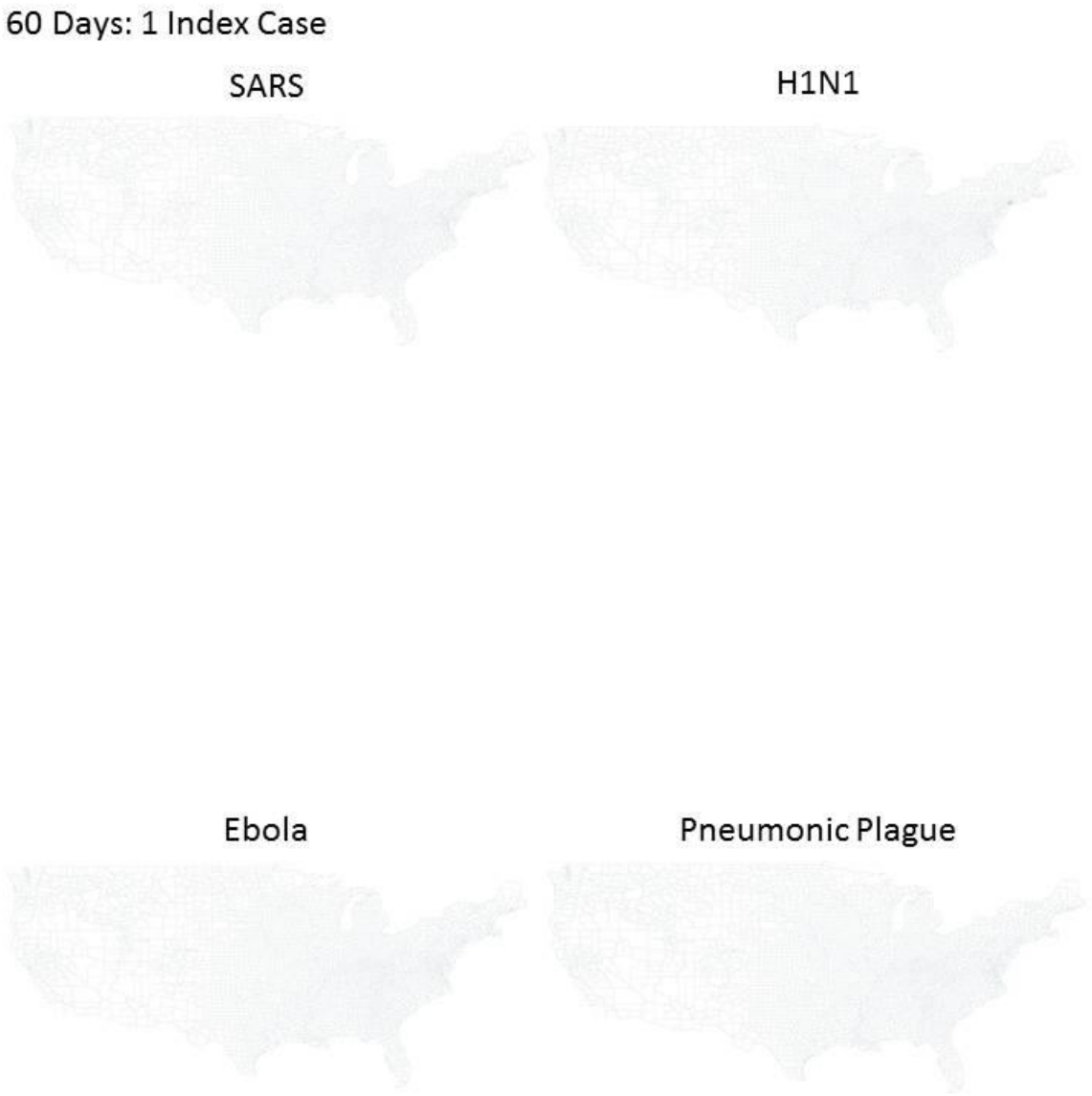


Figure 47 Ground Transportation: 60 Days (SARS, H1N1, Ebola, Pneumonic Plague)

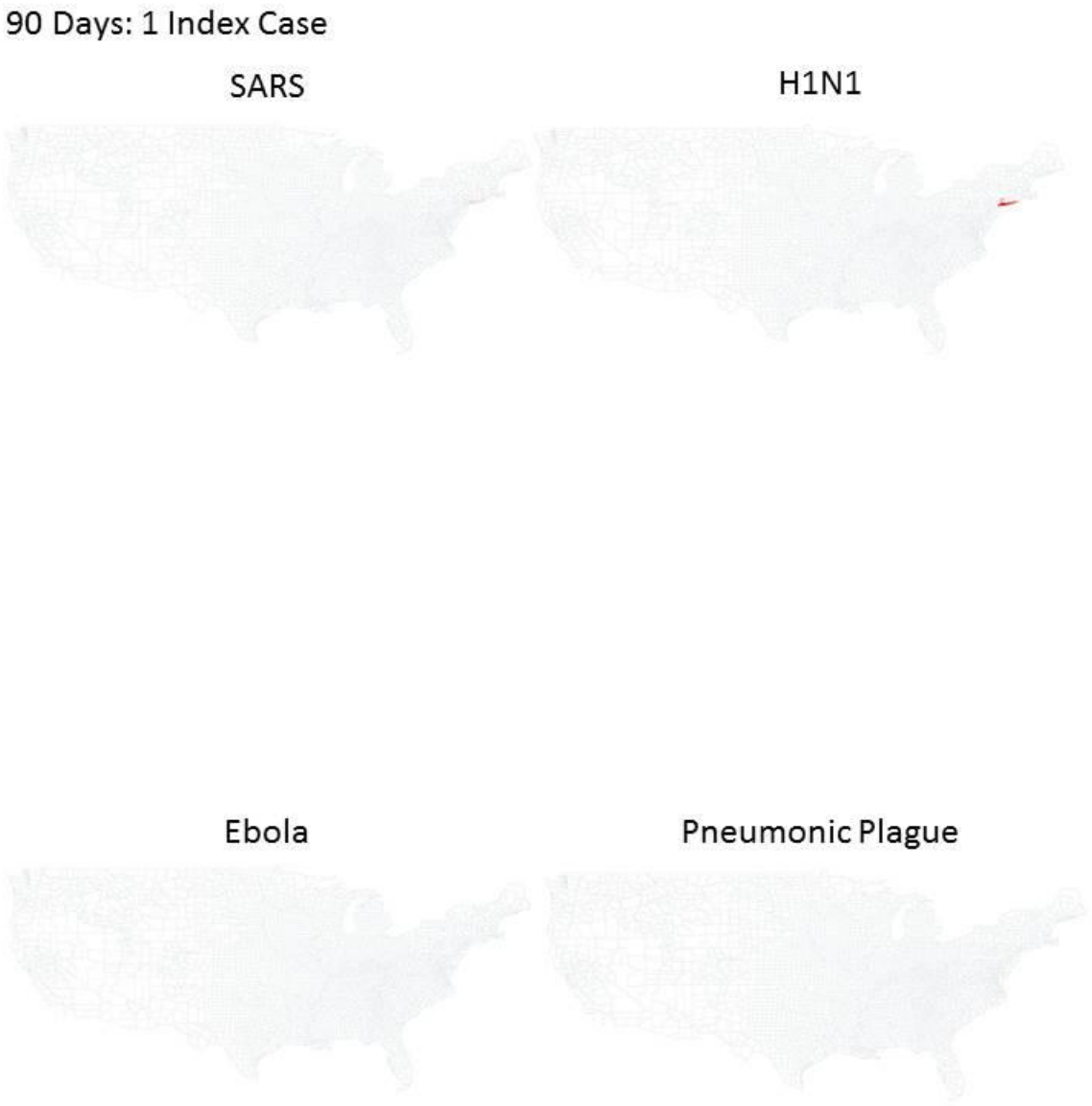


Figure 48 Ground Transportation: 90 Days (SARS, H1N1, Ebola, Pneumonic Plague)

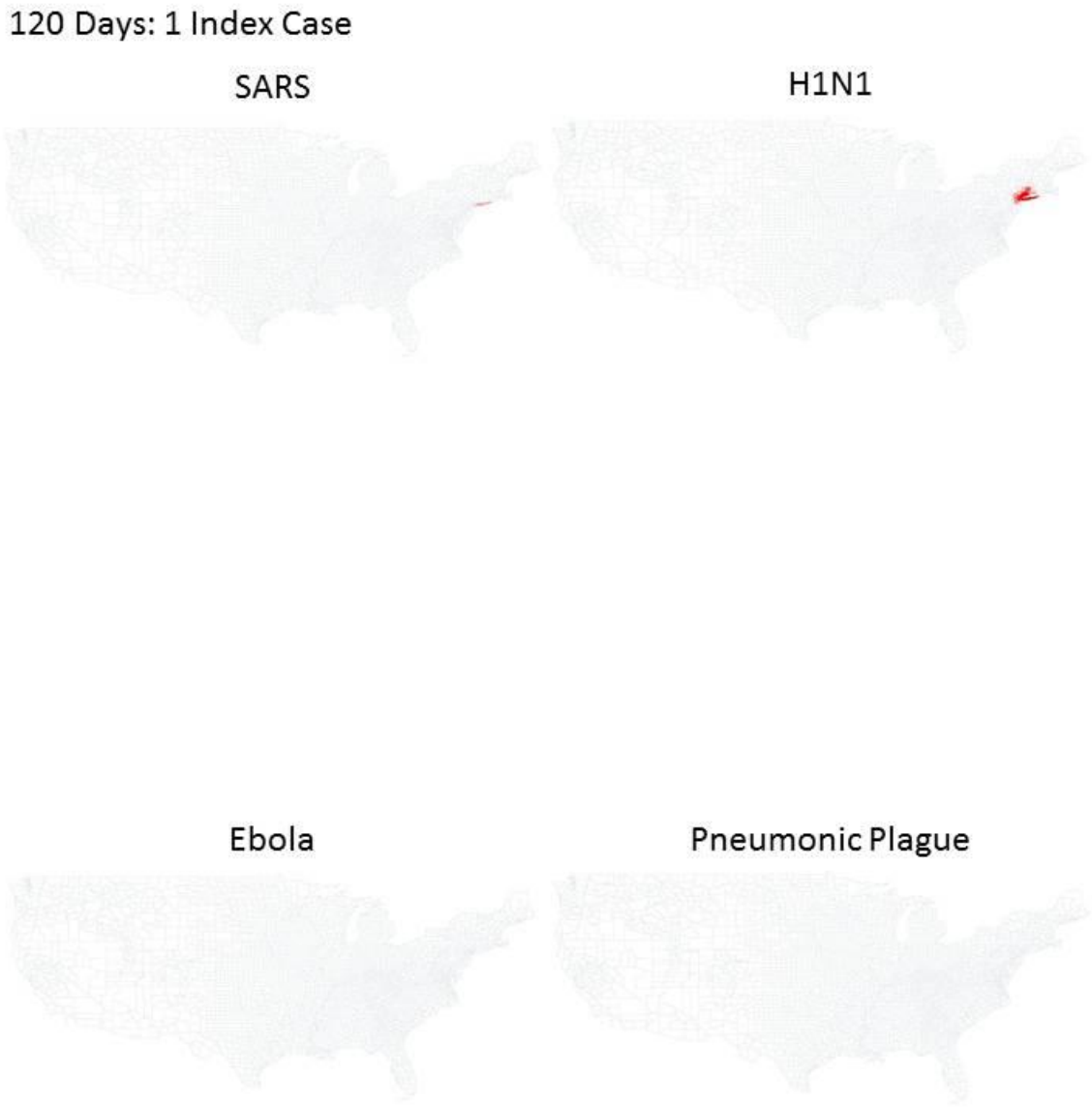


Figure 49 Ground Transportation: 120 Days (SARS, H1N1, Ebola, Pneumonic Plague)

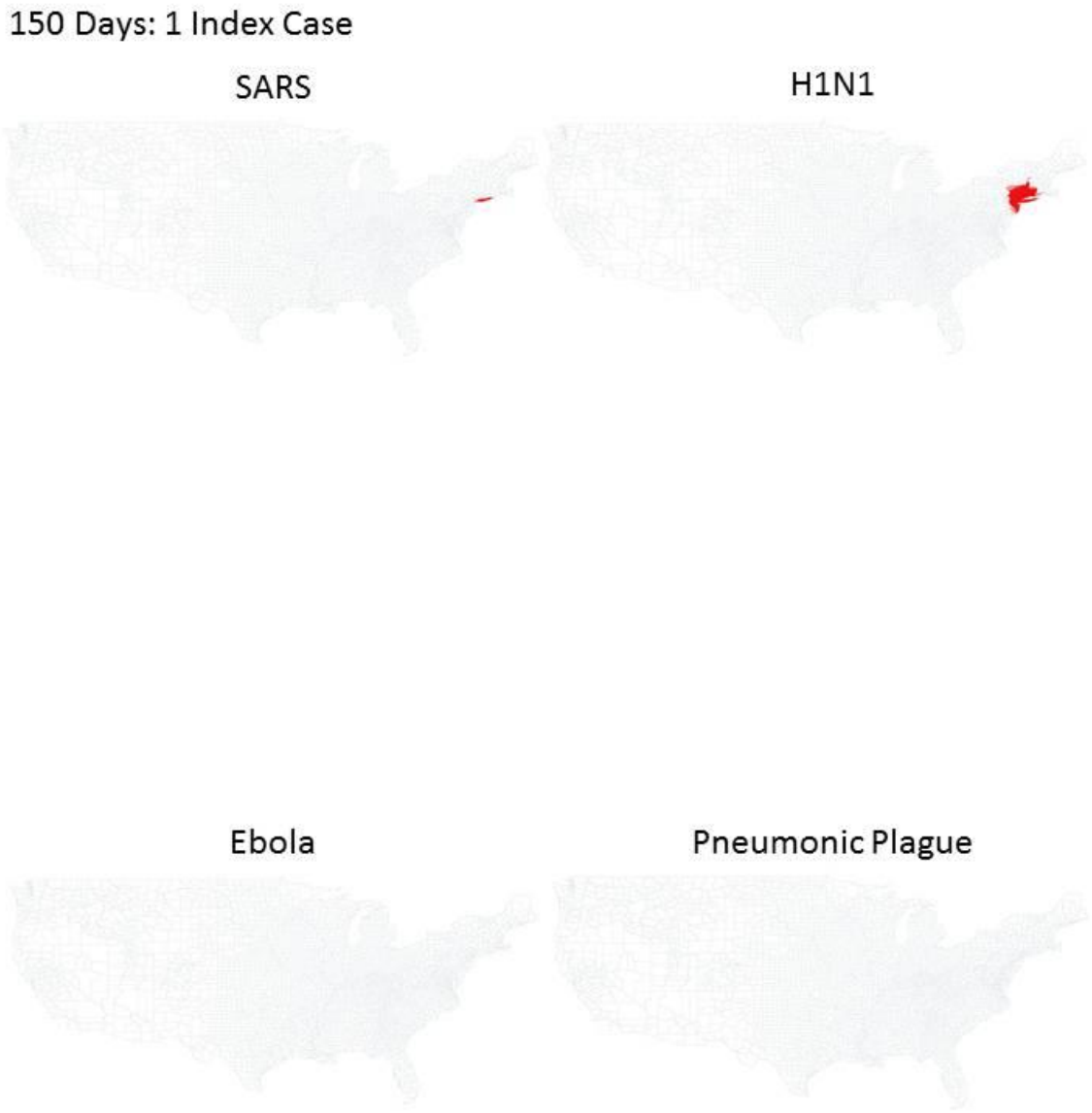


Figure 50 Ground Transportation: 150 Days (SARS, H1N1, Ebola, Pneumonic Plague)

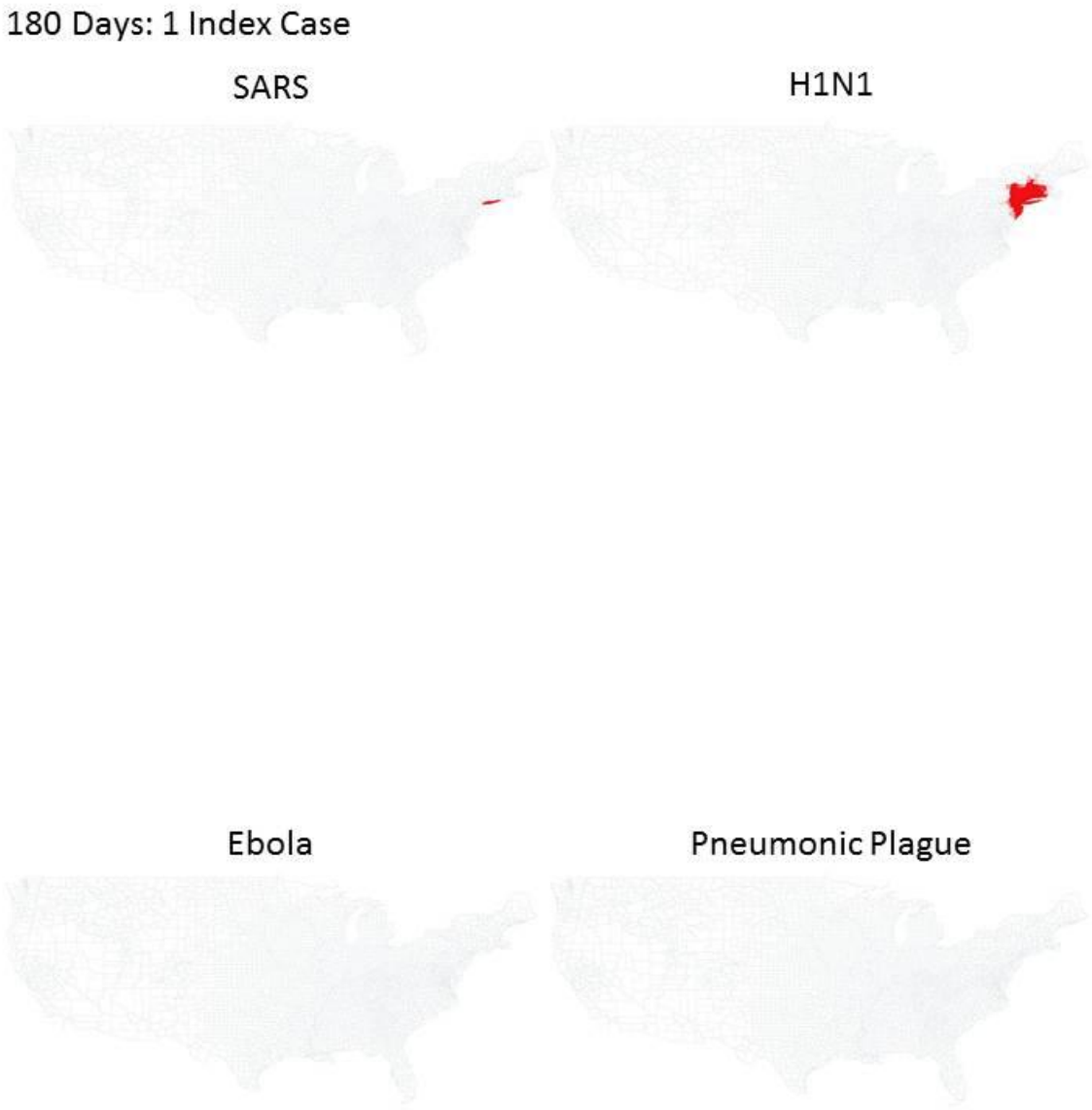


Figure 51 Ground Transportation: 180 Days (SARS, H1N1, Ebola, Pneumonic Plague)

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