



Modernizing and Expanding Outbreak Science to Support Better Decision Making During Public Health Crises: Lessons for COVID-19 and Beyond



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“If it’s something that we consider mission critical as a nation, what’s our plan? As a government, what’s our plan to enable that? If it’s like, ‘well, [we know a guy], and he’s over at BARDA, . . . and fortunately, we have a bunch of university modelers who are willing to do this without getting paid much,’ that’s not a plan. That’s not a capability.” (Senior USG official)

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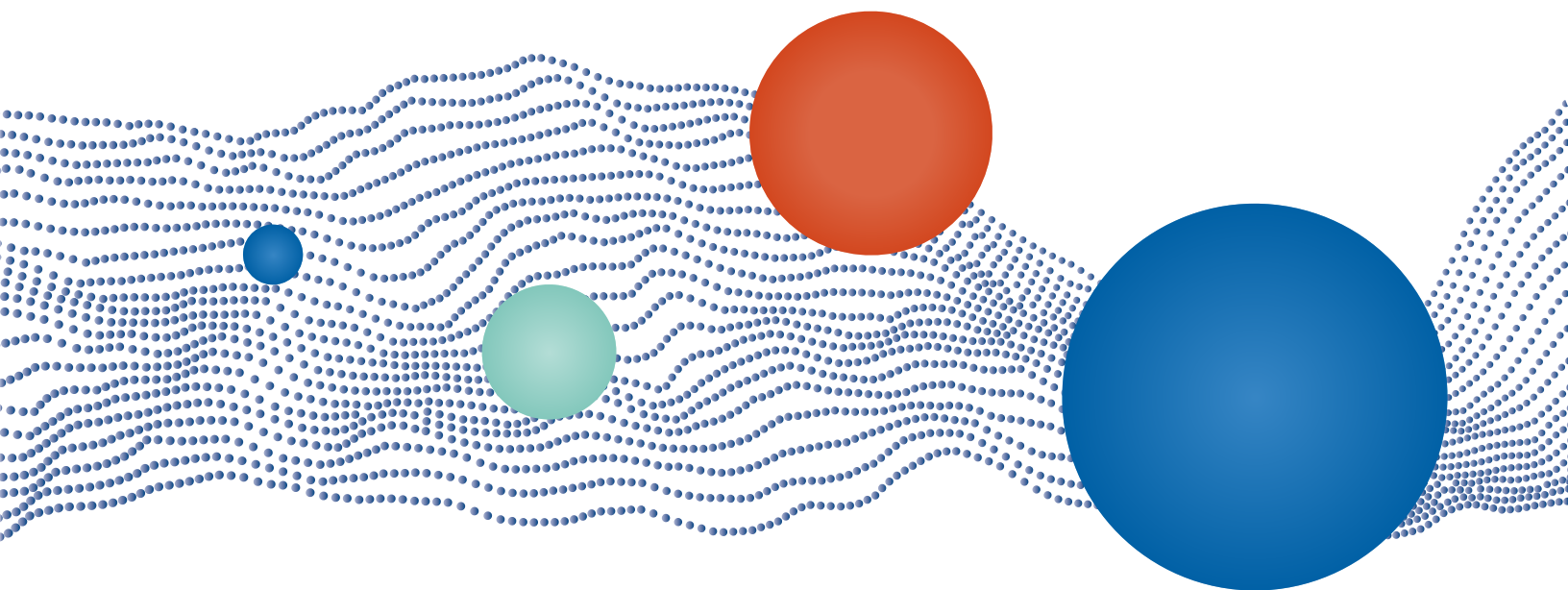
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MODELING FOR PUBLIC HEALTH DECISION MAKING DURING COVID-19

Beginning in January 2020, reports of the emergence of a novel SARS-like coronavirus in Wuhan, China, rippled through the global public health community. What began as a cluster of 41 people with atypical pneumonia has evolved into a Public Health Emergency of International Concern, with cases reported on nearly every continent. Now known as COVID-19, this ongoing outbreak is testing the world's ability to respond effectively to a severe public health threat.

During rapidly evolving infectious disease outbreaks like this, early understanding of the potential spread and severity of the outbreak can enable public health decision makers to take decisive action, even when data are scarce. Models are playing a prominent role in the ongoing COVID-19 response. The US Centers for Disease Control and Prevention and the World Health Organization have both organized teams, primarily comprised of academic modelers, to support the response. These efforts underscore the important role that outbreak science plays in informing public health practice during times of great need.

Nonetheless, more can and should be done. Despite the success of these COVID modeling efforts, there is room to expand and optimize the use of outbreak science in public health practice. As we detail here, there are gaps in our national capabilities that prevent the field from achieving its full potential. In this report, we review the challenges and opportunities facing outbreak science in the United States and propose a future direction to grow the field.



EXECUTIVE SUMMARY

The use of infectious disease modeling to support public health decision making, referred to in this report as “outbreak science,” has increased in prominence in the past decade. It has been used in the responses to several major outbreaks, from severe acute respiratory syndrome (SARS) in 2003, to H1N1 influenza in 2009, to the 2 most recent Ebola outbreaks in West Africa (2014-2016) and the Democratic Republic of the Congo (2018-current).

The purpose of this report is to characterize the origin and implications of the disconnect between modelers and public health decision makers and to develop a plan for the expansion of outbreak science as a capability to support public health. To accomplish this, we (1) conducted a literature review of past uses of modeling to support public health decision making, and (2) interviewed key informants from the modeling community and policymakers to identify themes and challenges related to using infectious disease modeling to support public health decision making.

We found that outbreak science is critical to the United States’ ability to prepare for and respond to outbreaks, but the current landscape is poorly structured. There is currently limited formal capacity within the federal government. Expert surge capacity exists in academia but leveraging those resources during times of crisis relies primarily on personal relationships rather than a formal mechanism. There is also inadequate support for the foundational work needed to advance outbreak science, which limits the growth and evolution of the field.

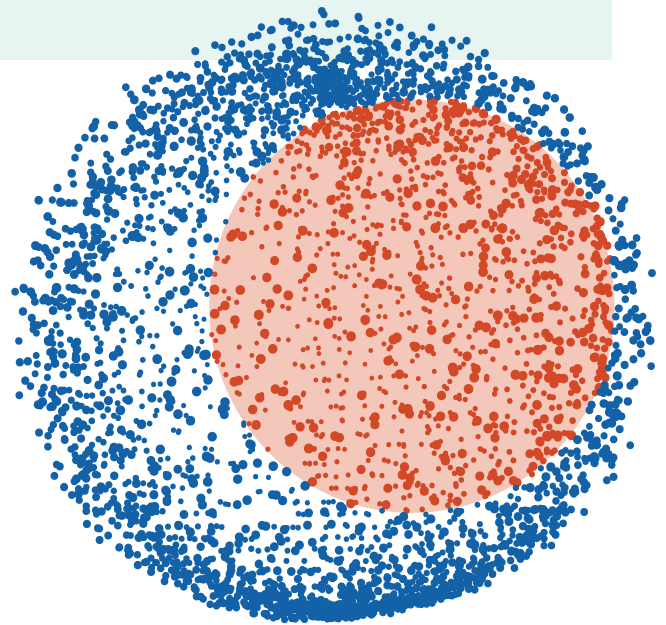
This report proposes potential approaches to addressing this problem. A first option is to create a permanent federal institution in the form of a new agency similar to the National Weather Service. This centralized service would serve the interagency, producing infectious disease analyses and advancing the foundational science. A second option would be to reinstate and redesign a previously existing capability comprised primarily of academics who served as experts on surge capacity in the event of an outbreak. A third option would be to employ some elements of both of these approaches. For this option, we recommend a life cycle approach, inspired by the CDC’s Epidemic Intelligence Service (EIS), in which outbreak scientists gain experience through 2-year field placements. Ultimately, as the COVID-19 pandemic underscores, modeling plays a key role in supporting decision making during outbreaks, epidemics and pandemics. For this reason, we must expand our national outbreak science capabilities in order to better prepare for and respond to infectious disease threats.

INTRODUCTION

The use of models to support US outbreak response has become more common. However, the current structure in the United States for using modeling for outbreak response suffers from a fundamental disconnect between the production of a forecast and the translation of that forecast into actionable decisions. Currently, modeling capacity exists primarily as individual teams of modelers within US federal agencies and an ad hoc network of academics who can offer their time and expertise during an outbreak response. Neither of these options comprise a formalized modeling capacity.

Our proposed working definition of outbreak science:
an interdisciplinary field to improve the implementation of models and critical data analyses in epidemic response to support public health decision making.¹

We undertook this work to identify gaps and opportunities in using infectious disease modeling to support decision making in outbreak preparedness and response. We then sought to develop a plan for the expansion of outbreak science as a capability to support public health. We did so by conducting an extensive literature review of previous uses of modeling to support public health decision making, as well as lessons learned from those collaborations. We also interviewed approximately 25 stakeholders from a variety of backgrounds, including academic modeling and public health decision making. These interviews were conducted before the COVID-19 pandemic. Although interviewees were primarily senior career experts, some junior and mid-career stakeholders also participated.



A semi-structured interview guide was developed prior to the interviews to help guide the discussion. All interviews were conducted on a not-for-attribution basis. Electronic notes were taken during each interview, and each interview was recorded with the participant's permission. After completion of the interviews, recurring themes were discussed among the research team.

Our work confirmed that there is a need to improve the field of applied epidemic modeling to enhance the capacity to use forecasts to support decision making during outbreaks. This report proposes mechanisms for improving the incorporation of epidemic models into outbreak response operations.

The findings and recommendations in this report are not necessarily the views of any of those interviewed for this report. The authors are solely responsible for the content of this report.

FINDINGS

Current Capabilities: Federal Government

At present there are a few small teams in the federal government with expertise in using infectious disease modeling to support public health decision making. Here we summarize current outbreak science capabilities in the federal government. However, additional expertise may exist as individual experts with modeling skills or in offices that contract with outside groups for modeling support.

Health and Human Services

Office of the Assistant Secretary for Preparedness and Response

The Department of Health and Human Services (HHS) Assistant Secretary for Preparedness and Response (ASPR) has a modeling and analytics division that previously supported the Biomedical Advanced Research and Development Agency (BARDA). This team specialized in questions around the development and deployment of medical countermeasures, both for infectious disease threats and other BARDA program targets. They also help decision makers to evaluate research or policy opportunities more broadly with quantitative assessments and visualizations.

For example, during the 2014-2016 Ebola outbreak in West Africa, there was an urgent need to expedite research and development for medical countermeasures, including vaccines and therapeutics. Modelers supporting BARDA were able to forecast expected future disease incidence to enable the design of sufficiently powered clinical trials.² After concluding there was a strong probability incidence would decline so much that clinical trials would not be able to enroll enough people, modelers assessed ways to optimize clinical trial enrollment. Members of the team have also been involved with working on pandemic influenza risk assessment, assessing healthcare needs during the Zika virus disease outbreak, forecasting chikungunya outbreaks, and estimating treatment needs of Ebola patients in the United States.³⁻⁶

Centers for Disease Control and Prevention

The US Centers for Disease Control and Prevention (CDC) has a long-standing group, the Health Economics and Modeling Unit, that supports programs across the agency. First formed in 2011, the unit is currently comprised of 9 interdisciplinary scientists who use quantitative analyses to support public health officials.⁷ During crises, modelers from the team participate in the Emergency Operations Center, where they can directly exchange ideas and information with decision makers. Their priority is to produce analyses in which the assumptions and results are easily displayed and available for interrogation. They can answer questions such as the expected trajectory of an outbreak if conditions remain the same, or what impact a given intervention may have. In the absence of major outbreaks, members of the modeling team assist with analyses for programs across the agency, not necessarily focused on questions related to infectious disease outbreaks.⁸ The team has also published dozens of studies on a wide range of topics, from pandemic influenza to vaccine-preventable diseases.

A notable example of modeling support provided by the CDC during the 2014-2016 West Africa Ebola outbreak was the projection of the number of cases expected in Liberia if the outbreak were to continue on its trajectory.⁵ During the H1N1 influenza pandemic in 2009, the CDC built models that estimated cases, hospitalizations, and deaths, which “provided leaders, policy makers, and the public with near real-time” data.⁹⁻¹¹ This was reported to have given decision makers “a picture of the pandemic up to that point, which was pretty different from what the impression people had from the surveillance data,” according to one key informant interviewed for this project.

The Health Economics and Modeling Unit is not the only modeling capability in the CDC. Other relevant modeling expertise exists, for example, in the Vector Borne Disease Branch, the Influenza Division, and the Center for Surveillance, Epidemiology and Laboratory Services.

Since 2014, the Influenza Division of the CDC has run an annual challenge, known as the “Forecast the Influenza Seasonal Collaborative Challenge” (aka FluSight), that invites the academic community to forecast seasonal influenza.¹² The training data and model targets (eg, the peak week and peak incidence) are shared among the participating groups. However, the modeling approach is left entirely up to the teams. This standardized framework allows forecasts to be directly compared for performance. The Influenza Division can then use these forecasts, either individually or together, to make assessments about the timing and severity of seasonal influenza. The division has included these results in their situation reports and briefings to senior leaders, which serves to both provide intelligence about possible future events and also familiarizes those stakeholders with modeling during routine decision making, thus paving the way for the use of modeling during emergencies.¹³⁻¹⁶

The Influenza Division further pioneered the use of outbreak science in operational public health when they announced two Influenza Forecasting Centers of Excellence in 2019. The goals of the centers are to “support applied research that will improve the accuracy and communication of real-time probabilistic forecasts for seasonal and pandemic influenza activity at the national, regional, and state levels. Accurate and timely forecasts should improve public health responses and inform policy development for pandemic and seasonal influenza.”¹⁷

Fogarty International Center at the National Institutes of Health

The Research and Policy for Infectious Disease Dynamics (RAPIDD) group in the Fogarty International Center at the National Institutes of Health (NIH) functions both as (1) a modeling capacity aiming to improve modeling of infectious diseases and improve their accessibility to public health decision makers, and (2) as a convening body, quickly bringing together workshops during outbreaks to support the response. RAPIDD has also conducted reviews of existing models in order to identify gaps.¹⁸ The group has contributed to merging the research needs from models with actionable information that policymakers need to make informed decisions. RAPIDD collaborators have contributed their modeling expertise to a number of emerging infectious disease outbreaks, including the 2014-16 Ebola virus outbreak, Zika virus, and MERS-coronavirus.¹⁹⁻²¹

Fogarty scientists have also led work to advance the state of the science. RAPIDD hosted an Ebola modeling challenge that asked participants to produce forecasts with synthetic data meant to simulate an Ebola outbreak under several different conditions. The performance of different modeling approaches was compared to the simulated data, with the finding that an ensemble approach was most accurate. In a publication describing the challenge, the team leads suggest that “peace time” challenges are important for improving forecasting methodologies and for improving coordination and collaboration that could be valuable during a public health emergency.²²

Current Capabilities: Academia

There are dozens of academic labs studying infectious disease modeling, disease dynamics, and other related questions. Many in the academic modeling community have participated in the Modeling Infectious Disease Agent Study Network (MIDAS) of the NIH. In the original version of the network, a limited number of top modeling labs (deemed MIDAS “Centers of Excellence”) were awarded funding for infectious disease model research and development. Funded institutions included the Harvard School of Public Health, the Fred Hutchinson Cancer Research Center, and the University of

Pittsburgh. As part of their funding package, they were also obligated to provide modeling support to public health decision makers in the event of an emergency.

This capability came in handy in 2009 when the detection of avian influenza (A H1N1 influenza) in Mexico raised concerns of a severe pandemic. The 2009 H1N1 outbreak was “the first time that models could contribute to a worldwide emergency response to a major infectious disease threat.”²³ Advances in computational modeling and new in-house modeling capabilities meant that decision makers had access to information unavailable in the past. The MIDAS network contributed in multiple ways to the H1N1 outbreak response, including modeling of social distancing measures, infection prevention and control measures, vaccine interventions and priorities, and the role of antiviral medications.²⁴⁻²⁹ A retrospective assessment of the use of modeling during the H1N1 pandemic found that, in general, models were more useful for determining the most effective interventions and healthcare capacity needs than for accurately predicting the course or severity of the H1N1 outbreak.²⁸ However, modeling early in the outbreak did help to establish the H1N1 strain as a potentially severe pandemic, which helped to inform the World Health Organization’s response.

More recently, members of the MIDAS network responded to the 2014-2016 Ebola outbreak in West Africa. For many in the network, their participation stemmed not from a mandate or direct request from decision makers but from a recognition that their skills could be helpful, coupled with a strong desire to help. In order to minimize duplicative efforts and receive feedback on early results, MIDAS program manager Dr. Irene Eckstrand organized weekly conference calls for network members. Although some individual teams had formed relationships with decision makers, many of the results from those efforts were communicated to public health counterparts indirectly through the academic literature.

In 2017, the translational aspect of MIDAS that enabled modelers to support public health decision makers was determined to no longer fit with the mission of the National Institute of General Medical Sciences (NIGMS), which focuses on funding basic science. The grant mechanism that funded both research and public health response was replaced with one limited strictly to research activities. Thus MIDAS-funded laboratories can no longer use their program funds to participate in outbreak response.

“So, I think it was really a very, very inopportune time that MIDAS funding went away, because it was right when that first crop of people that had been trained by the program were junior faculty . . . and now there’s no money for them to continue doing this work that we all learned and became passionate about.”

With the loss of MIDAS funding, there is little to no financial support for academics in the United States to participate in an urgent public health response. Many researchers interviewed for this report cited a lack of funding mechanisms as the largest barrier to having a modeling capacity in place for outbreak response. In fact, many felt that even the capabilities of the recent past would no longer be sustainable given these gaps. Many of the public health decision makers interviewed for this report were unaware of these changes to the program. They had come to see the network as a resource for modeling capabilities. Under the current paradigm, that will no longer be possible.

Even in its previous incarnation, the MIDAS model was not perfect. The connection between the two stakeholder groups often accessed only during times of public health crisis, when relationships could have been solidified and mutual understanding built. There was also no easy way for MIDAS modelers supporting the federal government to access data and information that was “for official use only.” Although such arrangements were and are possible, they are onerous and difficult to implement in the midst of an emergency; this meant that highly valuable outbreak-related data were not available to the modelers. This gap limited the ability of the outbreak scientists to do their best work, because they had to rely on out-of-date, aggregated, publicly available data.

Gaps In the Current Capacity

Through our interviews and analysis, we have identified the following gaps in our national capabilities.

No formal mechanism to access resources or build relationships

Current outbreak science capacities are primarily ad hoc collaborations of academic modelers interested in applied infectious disease modeling.

Interviewees suggested that the capacity of the specialized teams working in government can be quickly overwhelmed during large-scale emergencies. Infectious disease modelers working in academia have provided valuable additional modeling support to the US government in past outbreaks. However, the mechanism by which that collaboration is formed between the US government and outside researchers is completely ad hoc. Currently, there is no formal way for public health decision makers to access modeling expertise (outside of the few federal agencies that have modelers).

Poorly aligned incentives

Most outbreak science capabilities currently reside in academia. However, the incentive structure of academia complicates the participation of academics and fosters distrust between academic and public health partners.

Many respondents, both on the academic and public health sides, reported that the academic incentive structure was a major barrier to improved collaboration between the 2 fields. Academic careers are built on publishing papers; without a continuous pipeline of new papers, academics cannot continue in their jobs. To be clear, most academic modelers interviewed for this report wished it were possible for them to set aside that job requirement in order to help in the response. Some even do so, risking career consequences. But continuing to do so is not sustainable for them and thus not desirable. In contrast, public health professionals engaged in an outbreak response are rightfully mission oriented, focused on containing the outbreak. Although they recognize that the academic literature is important for sharing knowledge with the rest of the community, contributing to that literature is secondary to the task at hand.

This is a tricky dilemma. Even if they are personally motivated to help, it is difficult for academics to justify participating in activities that are both unfunded and do not result in the papers they need to continue in their careers. On the flipside, there is wariness in the public health community, particularly in countries historically marginalized and excluded from participating in international scientific conversations, that academics are only in it for the papers. There is also widespread concern, which in the past has been justified in many cases, that academics may use data without giving

appropriate credit and that they are only participating in the response in order to further their own careers.

No funding to support the expertise

Financial constraints are a major barrier to outbreak response, and the current funding climate is unsustainable.

With the loss of flexible MIDAS funding that could be used for outbreak response activities, there are very few opportunities for grant funding in this space. The National Science Foundation and the NIH, the 2 primary public grant-making organizations, support basic science rather than translational or operational work. Their funding programs are designed to support research activities with traditional academic outputs, like manuscripts. They generally do not react to urgent events like outbreaks or support academics working on applied or translational problems.

For relevant academic programs that do receive grant funding that allows them to work in this area, there is constantly a tension between maintaining baseline capabilities and requirements to expand into new projects or areas in order to secure additional funding. Furthermore, most grant-making organizations wish to fund innovative and exciting work, rather than continuing to fund sustainment projects, such as methodological evaluation. While the CDC occasionally makes awards in modeling and analytics to support decision making, that funding has not been used to create a sustained national capability. Currently, there are no US-based private foundations that make regular financial contributions to work in this area. (In the UK, the Wellcome Trust has supported outbreak science work, and they do sometimes fund groups from the United States.)

This lack of funds has a dramatic effect on the ability of academic modelers to participate in outbreak science activities. Many respondents we interviewed stated that it is not just academic activities related to outbreak science that are underfunded. There are projects that would be useful for foundational efforts to advance the science that have no obvious sources of financial support. For example, there is no entity responsible for archiving forecast predictions (more details on this can be found later in this report). It is not an academic function to perform such work, and no government program has made that part of its mandate.

This funding gap is especially pronounced for junior scientists. The original MIDAS program trained a generation of modelers interested and skilled in supporting public health. This newer MIDAS framework has no mechanism for outbreak science funding or building connections with decision makers. Without support and infrastructure, the capacity built during the original MIDAS will be lost, and new capacity will not be built. This gap will become increasingly apparent in the coming years when the most senior modelers prepare to retire. The junior modelers are building their independent careers at a time when the infrastructure that they trained under is being dismantled. With the restructuring of the MIDAS program, the next generation has nowhere to plug in.

“

“There’s definitely interest from the modelers. I think I’ve seen interest from the public health community as well. But the way academics function in the US, I mean, everyone is on grants, right? So, if you don’t have a particular dedicated line of funding to work on the challenge, then you do it on your own time.”

No access to data or operational intelligence

Models are only as robust as the data used to build them. Models built on data that are incomplete, biased, or otherwise poorly reflective of the realities on the ground will emulate those flaws, leading to high uncertainty or even inaccuracy.



“I think data is the biggest thing. I mean, having quantity and quality of data in a timely fashion is the lynchpin, and it’s the biggest challenge going forward.”

Our interviewees noted that stagnation in the quality, quantity, and speed of data is another challenge that has limited the evolution of outbreak science. This is particularly true for outbreak data like patient databases and contact tracing lists. In many settings, the infrastructure for collecting, collating, and cleaning high-quality data is underdeveloped. In the midst of an outbreak, it is difficult to create and implement data collection systems de novo; ideally, the surveillance systems in use in between major outbreaks could be leveraged for the outbreak response. In many locations, however, those systems either do not exist or are not robust enough for use during public health emergencies.

In our research, we found that even for the data that are collected, facilitating access between modelers and the accountable public health authorities is difficult. The data are wholly owned by the jurisdictions affected by the outbreak; any access to those data must be approved by the data owners. Although critical for maintaining proper control and provenance, this framework can sometimes become a bottleneck. Additionally, access to data is often dependent on “personalities, motivation, and obligation, and reputations to some degree,” as one interviewee noted.

The resources available to devote to collaborations are much diminished when faced with the demands of an outbreak. Furthermore, there are many more who wish to use the data than any public health ministry can reasonably correspond with, even if they wanted to. Ensuring the study designs are sound, that the data are correctly interpreted, that human subjects research principles and ethical guidelines are followed, and that proper credit is given is an intensive process that limits the number of projects a ministry can explore. And for those collaborations that are entered into, facilitating data updates intensifies the commitment.

What is left, then, for many modelers or external scientists participating in a response is a reliance on publicly available data, usually in the form of situation reports. The regular publication of these reports is a great service by ministries of health. However, the reports are far from ideal as sources of outbreak data. They generally contain only counts at the province level, a much larger geographic scale than most outbreaks, which thrive in community-level hotspots. They also lack many of the data elements that could be useful in understanding the epidemiology of an outbreak.

Inadequate data hinder the response and make building and updating models difficult. Improving the quality and speed of epidemiological data would improve model outputs and in turn would better support decisions based on those models.

No foundational effort to advance the science

Not enough attention is paid to developing a foundational understanding of how best to approach outbreak science, so that when an outbreak does occur, the basic methodological foundation is prepared to do its best work.

The majority of academic modeling groups spend the bulk of their time on modeling projects not specific to outbreaks. It is that work for which basic science grant funding is available. When an outbreak hits, they may temporarily divert some or all of their attention to that urgent task, but when the outbreak passes, they must return to their regularly funded activities. This is also true for the few government modeling groups. More time, energy, and resources are required to help develop a foundational mechanism by which outbreak science can be conducted. Through our interviews, we have identified a number of specific gaps in foundational knowledge and infrastructure needed to formalize outbreak science. They include:

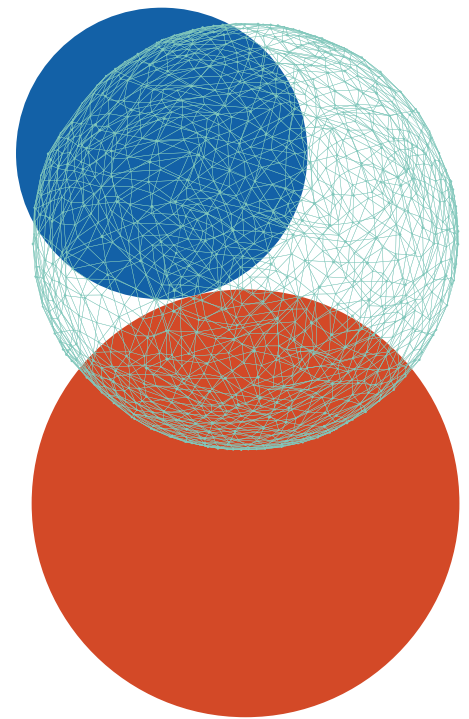
Archiving

The National Weather Service archives all of the predictions that it makes, as well as the eventual weather observations. It is this repository that is foundational to benchmarking how well meteorologist actually do in producing accurate forecasts at various time horizons. Although seemingly fundamental, this kind of work is not being done at all in the realm of outbreak science. There is no organization or team that keeps track of what predictions have been made and what actually came to pass. Indeed, there is little recognition in the community that this is even a task that needs doing.

Methodological investigation

When producing forecasts and other outbreak science products, there is a core toolkit of modeling methodologies and approaches that researchers rely on, such as compartmental models and time series analyses. There are also a variety of approaches for parameterizing models and visualizing the output. There is only a nascent understanding by outbreak scientists of which of these approaches is best and under what circumstances. Expert modelers have an intuition about the most appropriate or accurate methodologies given the constraints of a particular outbreak, but rarely has that intuition been formalized or tested against evidence.

Most of the work in this domain has been done under the auspices of “challenges,” some of which we have already described. For a challenge, modeling teams receive the same data sets (and are often allowed to supplement with additional data sets) and a set of targets, like peak week and peak incidence, that they must forecast against. The results of each team’s forecasts are compared against observed data, thereby allowing comparison of different approaches. An expansion of these challenges, ideally with funding to support participation, would be highly valuable for advancing the state of the science. Academic research programs focusing on similar inquiries would also be very valuable. Unfortunately, funding is not readily available to support either of these ventures.



Data requirements

Currently, data used for forecasting during outbreak responses are suboptimal in quality and often unavailable. During an outbreak response, line lists and other data sources are incomplete, and there are hurdles to obtaining data sources from responding organizations due to lack of data-sharing agreements and in-country confidentiality concerns. However, the path forward for improving that data has not been enumerated. What data elements are needed and at what spatial and temporal resolution remains unclear. It is usually true that the more detailed and resolved the data are, the better. However, it is not always possible to share individual-level data. On the other hand, the highly aggregated data reported in, for example, situation reports is often not detailed enough to be useful for building models. A more specific, research-informed understanding of the minimal data set required to produce models of specified outputs would be valuable. Without funding opportunities for academic modelers, there are few opportunities to complete these projects that are stagnating the advancement of the understanding of methodological and data set requirements.



“I’m thinking about potential opportunities for graduate students or students to be engaged and to have exposure to the [Emergency Operations Center (EOC)] and to have exposure to public health emergencies. Because I know from my training experience, that’s something that was not included in any of my graduate work training. And that’s something that could be really beneficial for workforce development as we think about a more capable workforce to be able to draw upon to go into the EOC.”

Training

Given that most outbreak scientists are primarily focused on doing research projects (rather than applied public health work), it is no wonder that the pipeline for training the next generation of outbreak scientists is not purposeful. Those who are in training for traditional modeling when an outbreak occurs may get a de facto education in outbreak science by assisting their lead investigator in outbreak modeling activities, but there is little to no planning around what should go into that training, or alignment of investigators and trainees interested in doing that type of work. Furthermore, there are no structured opportunities for outbreak scientists at any career level to cross-train in applied public health—for example, by participating in an Emergency Operations Center (EOC). This apprenticeship model is workable but needs additional structure and purposiveness to truly prepare trainees for a career in outbreak science.

Capacity building

Similarly, there are no programs currently available to train scientists and public health practitioners in low- and middle-income countries in outbreak science methodologies. Although capacity exists in the form of expert epidemiologists and biostatisticians, graduate school training programs are generally not focused on producing infectious disease models and could be expanded to better support outbreak response.

RECOMMENDATIONS

Establish a National Infectious Disease Forecasting Center



“I think having that kind of central authority would be really important. We know that that’s a big part of the reason that weather forecasting has become what it is, so there’s a very easy model to point to there.”

This approach would create a centralized organization in the federal government with responsibility for developing and using outbreak science to support public health decision making. The proposed agency, notionally known as the “National Infectious Disease Forecasting Center,” would serve the interagency and function both during and between outbreaks. The functionality of the forecasting center would be akin to that of the National Weather Service, which was established in 1870 and conducts weather forecasting and research.

During an active infectious disease outbreak, the forecasting center roles and responsibilities would include:

- Producing forecasts and analytics to support public health decision makers. This could include forecasting the trajectory of an outbreak, evaluating what public health interventions might have the greatest impact, determining the power needed for vaccine trials, and deciding how to allocate limited resources such as vaccines and other therapeutics, among others.
- Collating and standardizing outbreak data: the quality, quantity, and timeliness of data during outbreaks is often suboptimal to support outbreak modeling. The forecasting center would help establish a centralized location for data aggregation, standardization, and analysis.

During peacetime, the forecasting center roles and responsibilities would include:

- Encouraging the development of data innovation, including improving the speed and quality of outbreak data.
- Developing new methodologies and approaches for outbreak science in the context of challenges facing outbreak response (eg, data scarcity).

Archiving forecasts and undertaking critical analysis of the performance of outbreak science—for example, production accuracy and utility of outbreak science products—and identifying and assessing effective communication methods to better relay the major findings of outbreak scientists.

The forecasting center would be interdisciplinary, consisting of individuals with expertise in computational and infectious disease modeling, data science, and statistics. Because of the need to translate outbreak science modeling results into actionable interventions by public health decision makers, communication specialists would also be an important component of the forecasting center. Establishing and maintaining relationships with public health decision makers would also be important, to help ensure that the needs of the operational components of an outbreak response are being adequately fulfilled by the forecasting center.

The idea of establishing a forecasting center was explored extensively with participants as part of the research for this report. Many participants, even a majority, supported the creation of a new agency and thought that doing so would be the best way to truly realize the potential of outbreak science as a field. It would eliminate the disjointed and ad hoc mechanisms that have been stood up during previous outbreaks, allowing experts to focus solely on conducting outbreak science during outbreaks, and improving the field during peacetime.

However, serious challenges were identified with no easy solutions. First, securing funding for the creation of a new entity would be difficult, particularly in today's funding climate. Congressional approval and line-item funding would likely be needed. It is important that this funding not be just a one-time allocation, but an ongoing budget item to ensure long-term sustainability of the forecasting center. While outbreak science is an extremely useful asset to have during an active infectious disease outbreak, continual development of the science is needed, which requires ongoing financial and institutional support.

Second, persistent questions about the proper organizational position for such an agency remain unresolved. For many, the CDC, as the lead agency for the nation's health and for outbreak response, would be a natural home for such an organization. However, there are many other agencies and programs in the federal government that have responsibility for responding to outbreaks and for making decisions about public health preparedness and response. For example, USAID and the Department of Defense were both active in the US government's response to the 2014-2016 Ebola crisis. Placement of a National Infectious Disease Forecasting Center in the CDC would potentially complicate efforts to make forecasting and outbreak science products available to all of the stakeholders across the interagency.

The National Weather Service, although created in a very different era, overcame this problem by placing the weather service in the Commerce Department, where it was able to serve a variety of stakeholders. Such a solution may be possible for this center. One possibility is to locate the center in the General Services Administration (GSA). While best known as the organization responsible for maintaining federal government physical resources, such as real estate and vehicles, the GSA also houses the organization 18F, which offers digital services to agencies across the federal government. 18F creates websites, software products, and other solutions for government programs. Besides escaping the traditional stovepipe model of government resources, 18F is innovative in various ways. They are structured more like a start-up than a government agency. Although the details of their business model and workplace culture are not important for the purposes of this report, the 18F approach to offering products and services useful to many government customers serves as a good example of how the National Infectious Disease Forecasting Center might be structured.

THE NATIONAL INFECTIOUS DISEASE FORECASTING CENTER: OUR VISION OF SUCCESS



Expanded Expertise

“[What is critical for outbreak science is to understand] who’s making the decision, how they’re making it, and how they’re used to making the decision, so that you can try and tailor the delivery of the results as close as possible to that.”

A national forecasting center would create experts in outbreak science who have a thorough understanding of epidemiology and the operational components of outbreaks. Relevant backgrounds include an advanced degree in a field like computational epidemiology, statistics, or physics; training or direct experience in building models to support outbreak response; and training or direct experience in field epidemiology.

These individuals would be flexible about working on problems challenged by imperfect or sparse data and comfortable working on tight deadlines. It is often the case in academia that studies are not initiated unless the data are adequate to answer a question with a high degree of certainty. If obstacles are encountered, the study timeline is extended. Neither of those is usually possible in an outbreak setting; the public health decision makers must act on a specific timeline, and the analyses must be available to support that decision despite any challenges.

These experts would be equipped with an intuition about or receptiveness to focusing on the right questions at the right time with the right granularity. There are times when a quick sketch of analysis is more highly valued than a carefully constructed, detailed analysis, either because the question requires only the former or because the timeline demands it. Building that intuition is an important attribute in an outbreak scientist.

These individuals would also be skilled at communicating with people who do not have expertise in public health. There are many stakeholders in an outbreak response, and an outbreak scientist should be able to clearly and effectively communicate to all of them, regardless of the listener’s subject matter expertise. This is a relevant skill not just for communicating results, but also for working with stakeholders to structure a modeling question appropriately.



“I think that the visualization and the condensing of results to meaningful policy options has been an area that has not been effectively developed, and it’s not an area that is academically supported, and therefore, it falls on people that are kind of fluent in both policy and modeling, and there are relatively few of those.”



Sustainably Funded

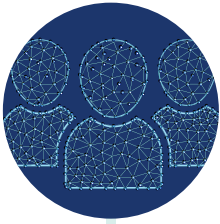
“The current paradigm has outbreak scientists jogging just to stay in place, constantly looking for grant funding to keep their doors open while volunteering their time to do actual applied work.”

The current paradigm relies almost entirely on grant funding, most of which is dedicated to basic science research rather than translational work. By establishing a forecasting center, funding would be:

Dedicated to maintaining current expertise in outbreak science and supporting the training of junior colleagues. Without this support, the field of outbreak science cannot be properly established or formalized.

Flexible in supporting modeling during active outbreaks and research during peacetime. A connection to the operational tempo of the outbreak response is critical for producing timely, high-quality analyses that are synchronized with the needs of decision makers. Funding during peacetime supports continued research on how to improve methodologies, data sharing and analysis, and other core components of outbreak science.

Sustainable to help ensure the long-term engagement of modelers in outbreak response decision making. This funding should not be tied to any particular outbreak.



Integrated with Public Health

“I really like the idea where modelers get to spend some time with the public health team in the context of an emergency, an outbreak in the field, or spending more time at HHS or the Ministry of Health, and again, there’s no clear funding for that. Although I know there’s some effort going on [at] WHO, in particular, to try to do more of that. But I think that’s really useful for modelers to understand what kind of problems and predictions they should make to be useful.”

Outbreak scientists should work closely with their public health counterparts to ensure that they are of greatest use to outbreak response activities. Establishing a national forecasting center would help ensure that relationships are:

Built through long-term collaboration. Connections between outbreak scientists and public health professionals are difficult to initiate and maintain remotely. Outbreak scientists should have an opportunity to embed with their operational counterparts, either in a field setting during an outbreak or in a public health department. Annual meetings to convene the 2 communities would also be useful for establishing that shared understanding. And although co-location is helpful at any stage of the collaboration, it becomes absolutely critical during an outbreak response, when decisions present themselves and must be acted on very quickly. When working remotely, it is difficult for outbreak scientists to remain engaged in the decision-making cycle and to grasp the less tangible attributes of each decision—for example, whether a detailed answer is needed, or whether a decision maker would respond better to a high-level answer or an in-depth briefing.

Dynamic and include relationships with other stakeholders beyond public health leaders. Laboratory staff, field epidemiologists, and logisticians, among others, all have important roles to play in the response and, in turn, with data collection. Proximity to these stakeholders is important for fostering relationships that will inevitably come in handy during times of need.



Innovative in the Field of Outbreak Science

“It’s peacetime now. So, let’s work on model development or model evaluation that’s going to help us when that day comes.”

During peacetime, outbreak scientists should be engaged not in unrelated modeling activities, but rather in the foundational work that is needed to improve the quality and timeliness of outbreak analyses. Work during peacetime in the national forecasting center might include:

Developing new models and methodologies to improve analytics or forecasting, skills needed for response work, data visualization and display strategies, and communication of best practices. For example, this might include algorithmic reconstruction of transmission trees and methodologies to incorporate new data sources.

Testing existing methodologies against observed data to find the most effective ones. Although there are studies under way in this area, additional focus on systematically identifying which modeling approaches are appropriate in various outbreak settings would allow for faster and more reliable modeling results to be produced when they are needed most.

Identifying new data sources and methods to clean data. As with testing, although innovative use of data in infectious disease modeling is an active area of research, much of it is focused on endemic or less urgent diseases and scenarios. Continued effort to improve the quality, timeliness, and spatial resolution of outbreak data specifically will also support faster and more reliable modeling.

Evaluating or auditing completed work. This would include archiving predictions and associated metadata in order to track prediction performance over time. Such archiving has been critical to pushing other predictive fields forward—for example, weather and economics. It is only when the field is able to systematically and rigorously evaluate its performance over time that it can reach its potential.

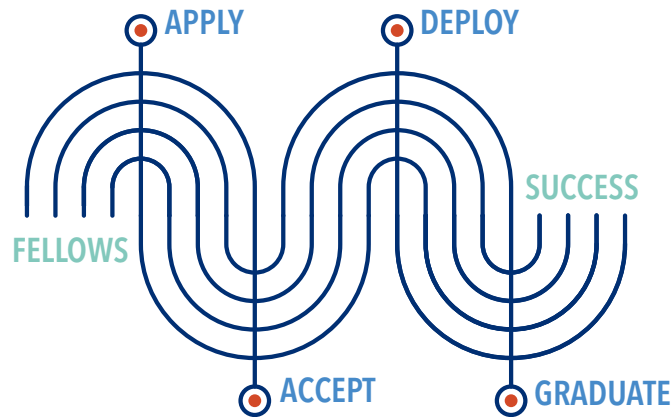
Conclusion

In conclusion, the establishment of a National Infectious Disease Forecasting Center would cement outbreak science as a critical component of modern outbreak management and would enable the growth and evolution of the field.

Supplemental Material

Appendix 1: Alternative Approaches

A National Infectious Disease Forecasting Center was not the only proposed mechanism for expanding outbreak science capabilities. Below are 2 other options discussed by the stakeholders.



Outbreak Science Fellowship Program

There are many fellowship programs that support embedded early- and mid-career professionals in the federal government. One of the most established is the American Association for the Advancement of Science fellowship, which embeds scientists in federal departments and agencies for 1 to 2 years. Another, CDC’s 2-year Epidemic Intelligence Service (EIS), is a globally recognized program in field epidemiology. Other examples, including the Presidential Innovation Fellows program and the White House Fellows program, also serve to bring energetic, dedicated professionals into government work who might not otherwise consider it as a career. It is in this tradition that we propose the development of an outbreak science fellowship program, where early- and mid-career scientists and modelers would be embedded with an agency responsible for decision making around infectious disease threats.

Acceptance into the program would be highly competitive. Applicants would need to hold a doctorate in a relevant field, such as computational epidemiology, statistics, or physics. Applicants should have pursued modeling, data science, or other relevant disciplines during their doctoral or professional work. A background in public health—for example, a master’s in public health or experience working in a public health department—would be desirable but not required. Those accepted into the program should intend to pursue a career in outbreak science and should be committed to helping to advance the development of the field. The agencies that host fellows should have direct decision-making authority over matters related to infectious disease threats. For example, this might include the CDC, the NIH, the office of the ASPR, the State Department, the Department of Defense offices with a health portfolio, and the Food and Drug Administration.

One challenge commonly faced by fellowship programs is that fellows are often expected to bring innovation to an agency without requisite knowledge about the priorities, operational tempo, and responsibilities of that agency. The purpose of this fellowship would not be to introduce outbreak science to the agencies. Indeed, it is quite the opposite. The purpose would be for emerging outbreak scientists to become accustomed to the priorities and requirements of the public health world. This familiarity is expected to help them to better align their modeling efforts with the needs of their public health partners during an outbreak response.

A core element of CDC's EIS program is that fellows are deployed in the field to investigate outbreaks, earning them valuable experience in “shoe leather” epidemiology. Similarly, participants in this outbreak science program should be given opportunities to deploy to the front lines of an outbreak response in order to learn about the challenges of that setting and to assist outbreak responders with data analytics. Although the placement agency would be encouraged to help arrange these deployments, the fellowship program could also work to secure access and would provide funding for the fellow to spend time in the field.

The benefit of this idea is that it brings outbreak scientists and public health practitioners together, allowing them to learn from one another. Outbreak scientists can gain exposure to the kinds of decisions that are made in an outbreak and the pace and context of those decisions. Public health practitioners can build a deeper understanding of the kinds of questions modeling can help to support and how to correctly interpret modeled results. The program would also serve as a structured training pipeline for the next generation of outbreak scientists to learn the ropes.

Potential Gaps

Although our proposal for a fellowship program would be an important step toward advancing outbreak science capabilities, it does not fill all of the gaps we identified while researching this important problem.

More funding is needed to financially sustain outbreak scientists in their “peacetime” work, particularly the infrastructure (archiving, software development) and methodological developments (data cleaning, modeling approaches for data-poor environments) that are unique to outbreak settings. We encourage program managers to consider how funding opportunities might be available to better support and grow these areas.

MIDAS Redesign

Another possible solution discussed by many participants is to reinstate and potentially refresh the previous MIDAS program, which had many useful attributes. Such a program would continue to feature a network of academic labs specializing in research related to using modeling for applied public health questions. The network would still be funded through grants that would allow for the development of models and other outbreak science products. However, interviewees noted that, unlike the current funding structure, the funding of a MIDAS redesign should also be flexible enough to allow modelers to drop their academic work and support public health decision makers in the event of a public health emergency.



Another benefit of the MIDAS program (in both its previous and current incarnations) is that it provided funds for training a new generation of modelers. Many graduate students and postdocs were recipients of these funds. Some of those trainees were involved in outbreak response activities. However, training was and continues to be primarily focused on academic activities, and so it was entirely possible for a trainee to complete his or her time in a laboratory without any exposure to

outbreak-related activities. A redesign should consider how to systematically train and expose young outbreak scientists to outbreak response operations.

Furthermore, previously there was no well-developed mechanism to connect modelers with decision makers, so many of those relationships were fostered on an individual basis rather than being tailored to the needs of each party. A redesign should also consider how better to connect these 2 critical stakeholder groups.

Ultimately, the project team found that a MIDAS redesign was neither tractable nor optimal. A reversion to allowing MIDAS-funded researchers to support public health practice is not achievable in the near future, and the gaps in the old-style model noted above are better addressed in an entirely different program design.

APPENDIX 2: WORKS CITED

1. Rivers C, Chretien J-P, Riley S, et al. Using “outbreak science” to strengthen the use of models during epidemics. *Nat Commun*. 2019;10(1):1-3. doi:10.1038/s41467-019-11067-2
2. Asher J. Forecasting Ebola with a regression transmission model. *Epidemics*. 2018;22:50-55. doi:10.1016/j.epidem.2017.02.009
3. Del Valle SY, McMahon BH, Asher J, et al. Summary results of the 2014-2015 DARPA Chikungunya challenge. *BMC Infect Dis*. 2018;18(1):245. doi:10.1186/s12879-018-3124-7
4. Dirlikov E, Kniss K, Major C, et al. Guillain-Barré syndrome and healthcare needs during Zika virus transmission, Puerto Rico, 2016. *Emerg Infect Dis*. 2017;23(1):134-136. doi:10.3201/eid2301.161290
5. Rainisch G, Asher J, George D, et al. Estimating Ebola treatment needs, United States. *Emerg Infect Dis*. 2015;21(7):1273-1275. doi:10.3201/eid2107.150286
6. Russell CA, Kasson PM, Donis RO, et al. Science Forum: improving pandemic influenza risk assessment. *eLIFE* October 16, 2014. <https://elifesciences.org/articles/03883>. Accessed February 23, 2020.
7. Centers for Disease Control and Prevention. Health Economics and Modeling Unit (HEMU). Reviewed November 18, 2013. <https://www.cdc.gov/ncezid/dpei/hemu/index.html>. Accessed February 23, 2020.
8. Centers for Disease Control and Prevention. Recent Projects. Reviewed November 18, 2013. <https://www.cdc.gov/ncezid/dpei/hemu/projects.html>. Accessed February 23, 2020.
9. Fischer LS, Santibanez S, Hatchett RJ, et al. CDC Grand Rounds: modeling and public health decision-making. *MMWR Morb Mortal Wkly Rep*. 2016;65(48):1374-1377. doi:10.15585/mmwr.mm6548a4
10. Reed C, Angulo FJ, Sverdlow DL, et al. Estimates of the prevalence of pandemic (H1N1) 2009, United States, April-July 2009. *Emerg Infect Dis*. 2009;15(12):2004-2007. doi:10.3201/eid1512.091413
11. Shrestha SS, Sverdlow DL, Borse RH, et al. Estimating the burden of 2009 pandemic influenza A (H1N1) in the United States (April 2009-April 2010). *Clin Infect Dis*. 2011;52(suppl_1):S75-S82. doi:10.1093/cid/ciq012
12. Centers for Disease Control and Prevention. FluSight: Flu Forecasting. Reviewed February 27, 2020. <https://www.cdc.gov/flu/weekly/flusight/index.html>. Accessed February 28, 2020.
13. Biggerstaff M, Alper D, Dredze M, et al. Results from the Centers for Disease Control and Prevention’s Predict the 2013-2014 Influenza Season Challenge. *BMC Infect Dis*. 2016;16(1):357. doi:10.1186/s12879-016-1669-x
14. Biggerstaff M, Johansson M, Alper D, et al. Results from the second year of a collaborative effort to forecast influenza seasons in the United States. *Epidemics*. 2018;24:26-33. doi:10.1016/j.epidem.2018.02.003
15. Reich NG, Brooks LC, Fox SJ, et al. A collaborative multiyear, multimodel assessment of seasonal influenza forecasting in the United States. *Proc Natl Acad Sci U S A*. 2019;116(8):3146. doi:10.1073/pnas.1812594116
16. Viboud C, Vespignani A. The future of influenza forecasts. *Proc Natl Acad Sci U S A*. 2019;116(8):2802. doi:10.1073/pnas.1822167116

17. University of Iowa. CDC network of Centers of Excellence COE to improve forecast accuracy and communication for seasonal and pandemic influenza. February 6, 2019. <https://grantbulletin.research.uiowa.edu/cdc-network-centers-excellence-coe-improve-forecast-accuracy-and-communication-seasonal-and-pandemic>. Accessed February 23, 2020.
18. Nelson MI, Lloyd-Smith JO, Simonsen L, et al. Fogarty International Center collaborative networks in infectious disease modeling: lessons learnt in research and capacity building. *Epidemics*. 2019;26:116-127. doi:10.1016/j.epidem.2018.10.004
19. Bellan SE, Pulliam JRC, Pearson CAB, et al. Statistical power and validity of Ebola vaccine trials in Sierra Leone: a simulation study of trial design and analysis. *Lancet Infect Dis*. 2015;15(6):703-710. doi:10.1016/S1473-3099(15)70139-8
20. Bogoch II, Brady OJ, Kraemer MUG, et al. Anticipating the international spread of Zika virus from Brazil. *Lancet*. 2016;387(10016):335-336. doi:10.1016/S0140-6736(16)00080-5
21. Chowell G, Blumberg S, Simonsen L, Miller MA, Viboud C. Synthesizing data and models for the spread of MERS-CoV, 2013: key role of index cases and hospital transmission. *Epidemics*. 2014;9:40-51. doi:10.1016/j.epidem.2014.09.011
22. Viboud C, Sun K, Gaffey R, et al. The RAPIDD Ebola forecasting challenge: synthesis and lessons learnt. *Epidemics*. 2018;22:13-21. doi:10.1016/j.epidem.2017.08.002
23. Lee BY, Haidari LA, Lee MS. Modelling during an emergency: the 2009 H1N1 influenza pandemic. *Clin Microbiol Infect*. 2013;19(11):1014-1022. doi:10.1111/1469-0691.12284
24. Cauchemez S, Bhattarai A, Marchbanks TL, et al. Role of social networks in shaping disease transmission during a community outbreak of 2009 H1N1 pandemic influenza. *Proc Natl Acad Sci U S A*. 2011;108(7):2825-2830. doi:10.1073/pnas.1008895108
25. Donnelly CA, Finelli L, Cauchemez S, et al. Serial intervals and the temporal distribution of secondary infections within households of 2009 pandemic influenza A (H1N1): implications for influenza control recommendations. *Clin Infect Dis*. 2011;52(Suppl 1):S123-S130. doi:10.1093/cid/ciq028
26. Lee BY, Brown ST, Korch GW, et al. A computer simulation of vaccine prioritization, allocation, and rationing during the 2009 H1N1 influenza pandemic. *Vaccine*. 2010;28(31):4875-4879. doi:10.1016/j.vaccine.2010.05.002
27. Lee BY, Tai JHY, Bailey RR, et al. Economic model for emergency use authorization of intravenous peramivir. *Am J Manag Care*. 2011;17(1):e1-e9.
28. Lee BY, Wiringa AE. The 2009 H1N1 influenza pandemic: a case study of how modeling can assist all stages of vaccine decision-making. *Hum Vaccin*. 2011;7(1):115-119.
29. Sharomi O, Podder CN, Gumel AB, Mahmud SM, Rubinstein E. Modelling the transmission dynamics and control of the novel 2009 swine influenza (H1N1) pandemic. *Bull Math Biol*. 2011;73(3):515-548. doi:10.1007/s11538-010-9538-z

APPENDIX 3: LIST OF INTERVIEWEES AND AFFILIATIONS AT TIME OF INTERVIEW

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