Guiding Health Care Policy through Applied Public Health Modeling and Simulation

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Abstract: The risk of a widespread epidemic is a primary public health concern with implications for healthcare providers and organizations. Modeling and simulation techniques have been successfully applied at the national level to set governmental polices and mitigation strategies through simulation-based predictions. Existing research in this field has been non-uniform in its coverage of local systems and region-specific findings. New collaborations between on the ground providers and modeling groups are required for successful simulation-based experimentation of region-specific health systems. These proposed collaborations are expected to contribute high-quality sub-population datasets to be used in experiments at the national level and allow for the reuse of existing disease models and simulation infrastructure in support of regional predictive experimentation.

Keywords: Public health, modeling and simulation, policy

INTRODUCTION

The threat of a global epidemic is an important public health concern. The modeling and simulation community has estimated that a pandemic influenza of a size similar to the 1918 Spanish flu outbreak would today result in 150 million deaths and a $4.4 trillion cost to global economic output (McKibbin 2006). The current state of unpreparedness would lead to overwhelmed health infrastructures and disrupted economies. This threat highlights the importance of incident response and policy at regional, statewide, national, and global levels. Public health planners at multiple levels of governance require methods to set planning strategies and predict the expected impacts of policies. Computational epidemiology is a field that studies the health of populations and spread of diseases. Modeling and simulation research groups in this community can help local clinics and regional hospitals in setting policies during an epidemic.

Public health officials at the federal level rely on simulation-based findings by computational epidemiology researchers to set public policies. Disease models, social networks, individual behavior models, public policies, and simulation systems are typically used to predict the effects of potential mitigation strategies on the course of a disease. Simulation-based experimentation can provide guidelines for public antiviral and vaccine distribution, private prophylactic use recommendations, distribution of pharmaceutical kits to selective groups (e.g., health care workers and children), individual behavior recommendations (e.g., masks, social distancing, staying home, and sequestration of the infected), hospital and healthcare utilization predictions, and community recommendations (e.g., local event and public school closures). The analysis of possible policies in these areas currently provides support for how to allocate resources, distribute pharmaceutical kits, minimize anticipated costs, and mitigate the spread of contagions at the national level.

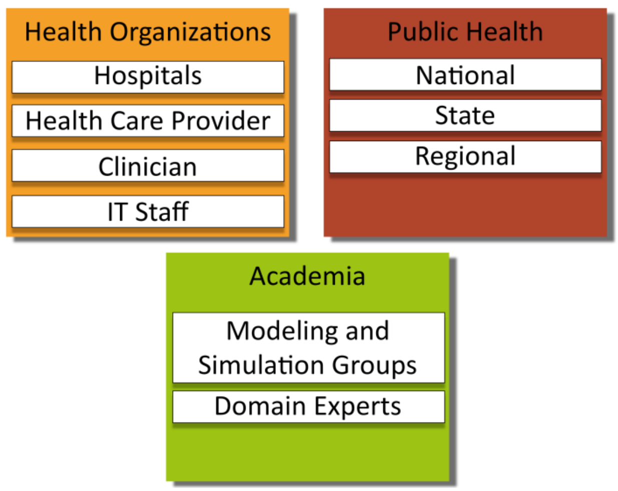
Similar efforts are needed to produce a body of scientific work to support various public health strategies and decisions at the local level. Specifically, best practices are needed to improve local health policies and to scientifically predict possible effects of decisions. Collaborations between simulation research groups and local healthcare experts are necessary to guide the regional priorities and strategies of public health and clinical systems.

PROJECTS AND SOFTWARE TOOLS

The development of epidemiology models and simulation applications requires the expertise of disease modelers, computational scientists, medical practitioners, public health officials, statisticians, mathematicians, physicists, and entomologists. Disease models, simulation software, and computational infrastructure are produced from extensive development efforts that are costly to duplicate between research groups. Designing and executing experimental studies using simulation and analysis software requires in depth knowledge of a particular simulation model and technical expertise. When done correctly, a simulation infrastructure and experimentation workflow may be used to predict the effects, cost, and plausibility of healthcare strategies. Several research groups have epidemiology simulation systems in place for experimentation at the level of regional, national, and worldwide scenarios. With currently available disease modeling applications, new studies must increasingly be conducted by area experts with detailed knowledge of local populations and available resources. To conduct simulation-based experimentation leading to real-world policy impacts, collaborations are need between medical experts at health organizations, modeling and simulation research groups in academia, and governmental public health agencies, shown in Figure 1.

A large body of existing tools and research exists in computational epidemiology. Disease models and simulation applications have been developed with support from organizations such as NIH Models of Infectious Disease Agent Study (MIDAS) and the Bill and Melinda Gates Foundation. The public health modeling community has developed numerous modeling and decision-making tools using distributed agent-based models and differential equations. These models have been used extensively in previous work to set policies for agencies including CDC, NIH, DOD, WHO, and the White House.

Figure 1
Minimal Collaboration Network



The diverse nature of vector-borne, contagious, and sexually transmitted disease models require specialized simulation applications. Two notable applications are FluTE, a stochastic influenza epidemic simulation model (Chao 2010), and OpenMalaria, a publicly available malaria simulation model (Smith 2006). Modeling and simulation techniques have been used at the Network Dynamics and Simulation Science Laboratory (NDSSL) to study the spread of diseases such as H1N1, H5N1, malaria, smallpox, and pertussis (whopping cough).

Public health researchers and officials have used NDSSL's existing simulation applications to determine optimal vaccine and antiviral distribution strategies, treatment and prophylaxis policies, targeted sub-populations, and dose guidelines. These applications have also been used to set policies for school and work closures, isolation of infected individuals, social distancing recommendation, public and sporting event closures, pharmaceutical kit selection, recommended family interactions, and potential public campaigns (e.g., hand washing, travel guidelines, and mask usage). The following are a representative sample of five isolated studies that have included local health case-reports and survey data in simulation-based studies of H1N1.

In Cauchemez (2009), data were collected from state and local health department case-reports. These reports included applicable clinical symptoms and demographic information of infected individuals. This tracking information was used in modeling the disease, how it spread, and provided recommendations for families with infected members.

Cauchemez (2011) demonstrates how models of local populations can be used in larger scale predictions. This study tracked the spread of infections starting in an elementary school in a semirural community in Pennsylvania. The school and community social networks were analyzed. The analyses lead to the development of transmission models to be used in future studies on the prediction of transmission considering targeted treatments.

Donnelly (2011) consists of analyses covering several local studies of H1N1 cases. The set of local studies includes staff, pupils, and family members associated with the New York City school system, a southeastern Pennsylvania school system, San Antonio high schools, and Houston school system. The study also included cases from an agricultural county on the Mexican border (Imperial County, California) and CDC national case-reports. This comprehensive study determined a recommended duration of isolation for infected individuals to reduce the onward transmission in future epidemics. These recommendations, along with recommendations for similar issues (e.g., school closures), feed into parameter calibrations of ongoing and future simulation studies.

In Chao (2011), simulation models were used to predict the seasonal timing and magnitude of epidemics in Los Angeles County. The study aimed to also predict the effects of public campaigns and timing of subsequent waves of infection. The results of the study provided a basis for developing appropriate response policies in Los Angeles public health departments and clinics.

Matrait (2010) is composed of a traditional comparison of vaccine allocation strategies. The findings of this study serve as a guideline for public health planners and services providers. The results detail which groups to treat with available resources and when to optimally distribute pharmaceutical kits during an epidemic.

The disease models and simulation infrastructure utilized by NDSSL are based on disaggregated agent-based network diffusion processes, now a *de facto* approach within the simulation community. The set of simulation tools produced by NDSSL includes EpiSimdemics public health disease modeling and simulation system (Barrett 2008), the EpiFast epidemiology simulation system (Bisset 2009), and the ENteric Immunity SImulator (ENISI) immunopathology modeling system (Wendelsdorf 2010). Over a dozen studies using these tools have been conducted at the national, statewide, city, and regional levels on behalf of several governmental agencies. These studies, at the granularity of individual persons, have included predictions of the spread of influenza through military and civilian populations in Alabama (pop. 4,600,000) as well as the spread of smallpox in Portland (Barrett 2005). Two related studies investigated the interaction between public and private behavior (Barrett 2009), as well as the infection and socio-economical impact of mitigation strategies based on individual demographics (Barrett 2011). The study presented in Barrett (2011) was conducted on the New River Valley (NRV) region in rural southwest Virginia (pop. 151,000). ENISI has been used to predict the inflammation and regulatory immune pathways considering interactions between individual cells and foreign bacteria in tissues such as the gut. The model is used by mucosal immunologists to test hypothesized mechanisms for predicting clinical enteric disease outcomes.

The current set of state-of-the-art modeling and simulation tools are widely missing local clinical information for most regions in the U.S. The few areas in the country with real world, high-resolution data on local health systems are generally located in the region immediately encompassing a modeling and simulation research group (e.g., Virginia Tech and University of Pittsburgh). Increasing the collaboration between research groups, clinicians, and area health providers would improve large-scale predictions as well as enable research in setting policies specific to a given area. As an example, information on a regional hospital's expected occupancy, capacity, staffing, patient throughput, and medicinal resources would greatly increase the accuracy and validation of simulated predictions that lead to the recommendations presented to health officials and providers.

OPPORTUNITIES FOR HEALTH CARE DELIVERY

Predictive simulations play an important role in setting public policies and now provide an opportunity to optimize practical health care delivery. Hospital modeling, health provider infrastructure modeling, local population modeling, and incident tracking are missing components in current public health research efforts. Systematic collaborations are currently needed between modelers and hospital IT staff to produce a comprehensive set of hospital and health provider models. These models would ideally be structured into a framework along with disease modeling and simulation systems to assist providers in disaster preparation. Specifically, the composition of disease and health provider models provide predictions on staff overload, resource shortages, capacity requirements, and patient routing during a disaster scenario. In some cases, these simulations also may be used to guide clinicians and practitioners in delivery activities based on the predicted high-impact procedures. Simulations also assist in non-medicinal planning by guiding recommendations that reduce the stress on health systems such as private behavior modifications, preventative measures, insecticide usage, and bed-netting usage (in tropical locations). Higher-resolution information on individual regions, when agglomerated at the national level, may be used to provide pertinent local public health recommendations while improving the accuracy of national studies. Littig (2007) provides a case study of the impact modeling can have on producing accurate predictions and advanced knowledge forecasts for future hospital occupancy and service requirements. This study used historical data from an area hospital to model inpatient census, occupancy by unit and shift, resource use and fluctuation, staffing requirements, bed management, ambulance diversions, and patient care quality. Including this information in disaster simulations provides predictions and suggestions on current areas of a health infrastructure that need improvement. The computing infrastructure provided by modeling and simulation research groups also eases communication and dissemination of findings to rural and poor regions and provides a central medium of reviewing previous studies; see SimDL, a simulation-supporting digital library (Leidig 2011). SimDL has been developed for the purpose of managing the underlying datasets, disease models, population models, experimental designs, study results, analyses, and publications for research produced through simulation systems. This digital library services as a portal for collaborations between healthcare providers who are contributing information on local health infrastructure and modelers, software developers, analysts, and public health officials. SimDL also serves as an access point for hospital managers, providers, and IT staff to discover recent predictive studies and recommended disaster planning policies. Previous experiences in malaria research have showcased the mutual benefits of collaborations between modeling research groups and area health providers; see Swiss Tropical Institute (Switzerland) and Ifakara Health Institute (Tanzania). While there are current epidemic surveillance and mitigation systems in place by state and national authorities, there is disappointingly little collaboration between public health researchers and health providers in setting epidemic-related policies.

ROLE OF THE HEALTH CARE PROVIDER AND IT PROFESSIONAL

The potential of intelligent disease modeling and mitigation will only be realized through the emergence of collaborations between health providers, provider IT staff, clinicians, modeling and simulation groups, and public health officials at all levels of government. Efforts by health care and IT professionals are needed to provide local datasets that will improve national and local health care modeling. By contributing data on local health systems, the accuracy and quality of health model are improved at the national level. In addition, this data can be used in micro-simulations that use existing high-quality simulation applications. By restricting the scope of the simulations to use only locally provided datasets, local health system planners receive access to previously unavailable simulation-based predictions and analysis of their systems. IT staff will need to play a significant role in providing anonymous and summarized patient data to modelers while adhering to internal privacy requirements. In the reverse direction, IT professionals will need to review predictions, made by the modeling community, of hospital utilization during a disaster in order for members of management to set internal policies. IT staff also play a role in the early identification and reporting of emerging diseases and epidemics through data organization and mining practices. The reporting of detailed inpatient modeling, similar to Littig (2007), in addition to published surveillance data by NIH and CDC, are necessary for the modeling community to conduct accurate simulation-based experimentation. Improving the quality and resolution of datasets used by existing modeling tools directly benefits health providers. The products of modeling tools are currently being used to set national policies, as previously discussed, and will provide a new class of simulation-supported findings in how health care providers should optimally utilize resources and recommend behavior modifications to patients (e.g., out-patient sequestering).

NDSSL's existing modeling and simulation software applications have been developed to execute on large-scale computing resources. These applications are capable of handling multiple disease models and underlying population data. New disease models and healthcare system models, when formatted correctly, may be directly utilized without any modifications to the simulation software. SimDL provides a point for storing and managing models of healthcare systems and the population each system supports. Each modeling and simulation group has developed custom formats for describing healthcare and population models. Unfortunately, model formats are currently incompatible between modeling research groups, although there have been some efforts to standardize and translate between formats. Direct collaborations are needed between individual healthcare providers and modeling groups to produce a new class healthcare models. NDSSL has previously produced population models based on census data and activity modeling. Individuals in these synthetic populations are attached with demographic information (e.g., age, income level, address, family size, and daily schedule). To produce a model of a healthcare provider, modelers and healthcare providing organizations must provide information related to descriptive capabilities (e.g., beds, staffing, and resources), usage history (e.g., baseline unit utilization and throughput), and the population served (selected as a subset of the existing U.S. population model).

Previous collaborations between several state health departments and the modeling community have successfully produced tools (e.g., simulation visualizations) that rely on hospital data and population information to inform disaster planning decision-making at the state level. In domains supported by computing efforts, data collected for one purpose may often be reused later in different contexts. The prediction and optimization uses of inpatient data along with hospital and provider capability modeling may have beneficial, currently unforeseen public health uses (e.g., tracking infections within a hospital). As a caveat learned from decisions at the national level, analysts at health providing organizations would do well to remember that setting antiviral and vaccine purchasing and distribution policies based on simulation studies must consider healthcare imperfections such as waste, misuse, and misdiagnosis.

CONCLUSIONS

Computational epidemiology modeling and simulation research has been extensively used to set national public health policies. Data and models covering the health systems, capabilities, and anticipated needs of local regions are generally unavailable. Higher resolution simulation-based experiments will require the widespread availability of regional healthcare system datasets. Several existing studies have shown the benefits these datasets have on predictions for multiple infrastructure planning and policy issues. Previous high-quality, high-performance simulation systems have required large amounts of federal and private funding. Development of state or regionally specific simulation infrastructures is unsustainable and impractical. Existing simulation tools may be made available to local planners and health care providers, given mutual collaborations in the experimentation process. To get involved in disaster planning and resource optimization processes, healthcare providers will need to contribute models of local health systems. These regional models of health systems and usage statistics may be plugged into existing public health simulation systems. The authors call for future systematic collaborations between health providers and leading simulation groups with previous experience in modeling health systems the national level.

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