Defining Disease Forecasting and Modeling

Disease forecasting is important in describing potential future outbreaks that will affect the population and demand for health services in a given geographic area. Forecasts pull input from various sources (e.g., disease models, demographic, mobility, and intervention impact data). Individual forecasts can also be part of an **ensemble forecast** to improve accuracy. Forecasts can cover any length of time, but most target a window of several weeks to a few months. A subset of forecasts, known as **nowcasts**, seek to estimate present conditions, or those expected to occur imminently.

Disease models are mathematical tools that are foundational components of disease forecasts. They estimate quantifiable factors that are impossible or impractical to directly measure, (e.g., future hospitalizations from a given disease, or its infection count in a population). Although models can be useful for specific questions, they do not give as complete a picture as a forecast. There are four major disease model types:

- **Mechanistic.** Attempts to simulate biological and/or social processes of transmission based on assumptions from prior or experimental data.
- **Statistical.** Relies on past data (such as infections or death) to predict future trends and can incorporate some assumptions about intervention application and uptake. Quality and quantity of past data can be a major limitation, and some models may suggest biological improbabilities.
- **Agent.** Simulates individual risks and behaviors in a population. These are highly complex, computationally very expensive to develop and run and require vast amounts of data and strong assumptions.
- **Ensemble**. Like their forecasting counterparts, they compile models and outputs, mitigating the risk of relying on one data point. While raising the overall confidence in output, they require coordination of many models to be built and simulated, which can be complex and costly unless the models already exist (such as for COVID-19 case counts).

Forecasts and Models Work Together

While disease forecasts and models are often conflated, they are discrete concepts. Forecasts offer a general prediction, whereas models are the mathematical pieces forecasters use to create them. Weather forecasts are commonplace, and their weekly predictions are often reasonably accurate. In contrast, predicting a big storm's individual factors (e.g., rainfall, wind speed, lightning strikes) fall to the job of models. Together, those models help meteorologists better understand the weather and generate a forecast.

In a public health context, disease forecasting informs public health officials, healthcare providers, and policymakers about potential risks and guide decision-making regarding preventive measures, resource allocation, and response strategies. Meanwhile, disease models aim to simulate the behavior of infectious diseases under different scenarios, allowing researchers to explore and evaluate various factors that influence disease transmission.

Considerations for Decision-Making

Decision-makers should consider scope and limitations of forecasts and models. They may consider adding inputs—such as projections for economic and long-term impacts. Examples include economic impacts of school closures, costs of more staffing ahead of an outbreak, and supply chain shortage forecasts for personal protective equipment (PPE). Decision-makers at all levels should consider using modeling to answer more specific, practical questions rather than predicting overall trends.

Forecasts can cover different geographic scales. Public health leaders will need granular, local data to most effectively inform decision-making and communications. Novel conditions and pathogens may not have readily available data to inform models or forecasts, which will affect their predictive ability. Health officials must effectively communicate these limitations to decision-makers and the public.

Examples of Forecasts and Models

- COVID-19 Forecasts: Hospitalizations shows the number of daily COVID-19 hospitalizations reported in the United States from the prior two months and projected daily COVID-19 hospitalizations over the coming four weeks. Information sources are independent teams meeting submission and data quality requirements. Information sources are independent teams meeting submission and data quality requirements.
- FluSight has many contributing teams and models that predict the upcoming weekly laboratory confirmed influenza hospital admissions both nationally and by state.
- Johns Hopkins University's Center for Systems Science and Engineering county-level risk model for COVID-19 in the United States. This model leverages epidemiological data, mobile phone data, demographic and socioeconomic information, and behavioral metrics.
- The Global Epidemic and Mobility Framework simulates the global spread of infectious diseases by mathematically representing infection dynamics, population geographies, and population mobility patterns.

Additional Resources

- Disease modeling for public health: added value, challenges, and institutional constraints
- Predictive Models for Forecasting Public Health Scenarios: Practical Experiences Applied during the First Wave of the COVID-19 Pandemic
- Applying infectious disease forecasting to public health: a path forward using influenza forecasting examples
- Technology to advance infectious disease forecasting for outbreak management

This brief was supported by Cooperative Agreement Number CDC-RFA-OT18-1802 2018-2024, funded by CDC. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of CDC.