The COVID-19 Pandemic

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Prepared by:

Health Policy & Public Health COVID-19 Advisory Panel
Department of Health Policy
Vanderbilt School of Medicine

Modeling & Forecasting to Improve COVID-19 Response

COVID-19 is rapidly spreading across the U.S., and forecasts from mathematical models support energetic and multi-pronged interventions to prevent the catastrophic outcomes seen elsewhere from occurring across the country.

What these models can tell us

Information on the COVID-19 pandemic is incomplete and changing daily. Given these conditions, mathematical modeling of infection is the best tool for population-level planning. The goal of modeling in this situation is to describe possible outcomes under various simulated scenarios, using the best available information.

For models to guide decision-making, it is imperative that they use data reflecting the most recent evidence. Valid models rely on accurate and timely data: however, waiting for perfect data to inform decisions is not an option. The current models consistently indicate that an uncontrolled pandemic would lead to a deluge of cases requiring intensive care that would exceed the current U.S. surge capacity.

We reviewed recent informative mathematical models related to the COVID-19 pandemic that can be used to inform decision-making. This review is not systematic and some of these reports have not yet undergone peer review.

Further, this review does not provide detailed description of individual parameters or assumptions used in each model, nor does it include reports that focus on models exclusively based on data from China or that do not have direct relevance for the U.S. Rather, this document provides a summary of observations from current models with an emphasis on findings that were consistently observed across different simulated scenarios and assumptions.

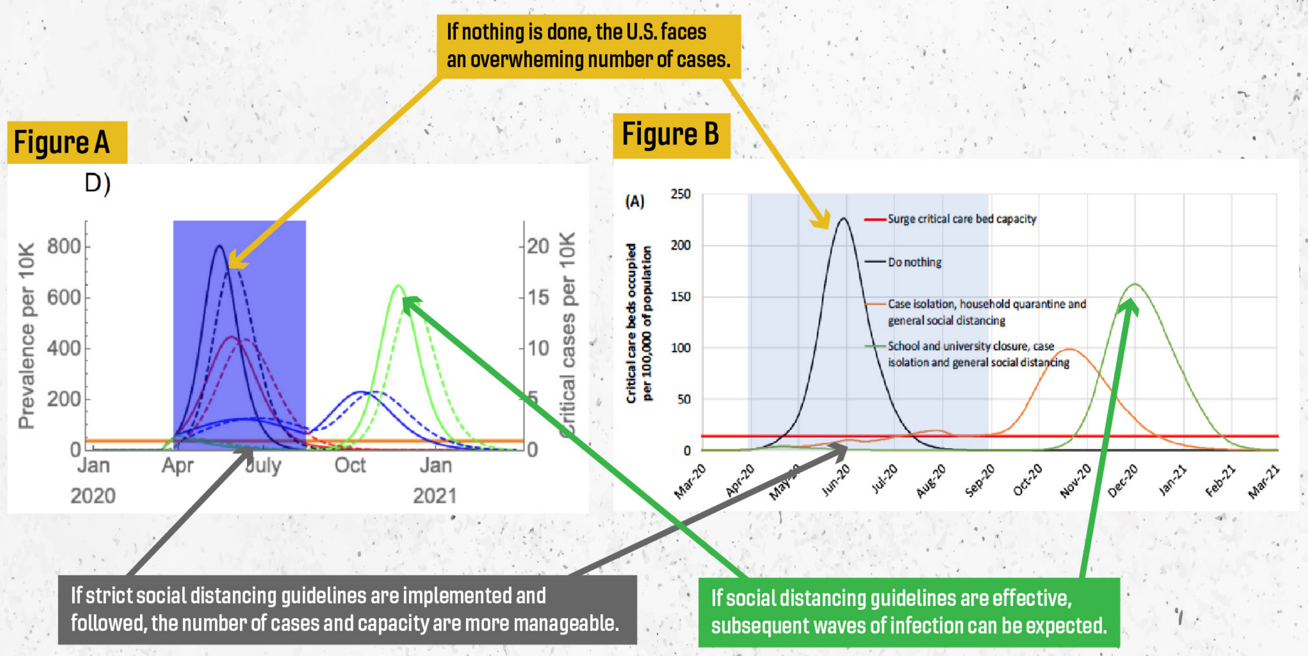
These models can inform effective public health strategies and responses, which we have covered in a separate memo.

What does this mean for our community?

- Mathematical models suggest that high levels of compliance with social distancing measures are needed to reduce transmission. The reduction in transmission is directly proportional to the intensity of the social distancing measures.
- If social distancing measures are effective, the burden on the healthcare system will be spread out and more manageable. Models predict increases in disease after removal of social distancing measures; intermittent reimplementation of these measures will need to

COVID-19 INTERVENTIONS: 2 MODELS, A SIMILAR STORY

These separate models consistently indicate that without interventions, the epidemic may overwhelm the critical care surge capacity in the United States. The figures illustrate the estimated impact of multiple interventions on modifying the expected viral activity in the absence of any intervention.



How to read these models

Figure A

Source: Kissler et al. (Harvard T.H. Chan School of Public Health - Center for Communicable Disease Dynamics, US)

This figure outlines the expected infections assuming no intervention (black lines), and 20%, 40% and 60% (red, blue and green lines) reductions in transmissibility attained by social distancing measures. Dashed lines represent critical care cases with their frequency represented in the right hand side axis.

Figure B

Source: Ferguson et al. (Imperial College, UK)

This model displays expected infections assuming no interventions (black line), and under scenarios with grouped social distancing interventions.

The shaded areas represent periods during which the interventions were simulated, from 20 weeks in A to ~22.5 weeks (5 months) in B.

What these models say

The models indicate that effective social-distancing measures could maintain the number of patients that need critical care below the surge critical care capacity (depicted as an orange or red horizontal line in the figures). In both representations, ***effective social distancing measures that make the burden of disease manageable also lead to limited population immunity, so that the models estimate subsequent waves of disease that may require additional social-distancing interventions***.

be considered.

- The models project that critical acceleration of disease will occur during the next 2 weeks, so the opportunity to continue implementing measures to slow the transmission is short.

How models can improve

The input data informing current models of transmission are incomplete and imperfect. Still, the main conclusions have been largely consistent across models. Specifically, they all reinforce the need for multi-pronged social distancing interventions. As new information is collected, models can be revised and new decisions can be made. While field epidemiologists are at the forefront of compiling new local data, research partnerships can support data collection, modeling and decision-making efforts targeted to local areas.

Given the dynamic nature of modeling, the availability of additional data will be critical for refining current estimates and calibrating interventions. Most current models specify the estimated effect of interventions on the simulations in a deterministic manner. Subsequent models allowing more realistic random variation (i.e. stochastic models) will be informative.

Below we summarize the most recent and comprehensive mathematical models of the COVID-19 Pandemic with implications for the U.S. These models include transmission and forecasting initiatives that have implications for decision-making.

Leading models:

1. Murray et al. (Institute for Health Metrics and Evaluation, US), examined projected deaths and excess demand for hospital services due to COVID-19 infections in the U.S. The model used information on reported deaths, hospital capacity and utilization to forecast deaths and hospital utilization for the entire U.S. and individual states over the next four months. Estimates considered existing policies for social distancing and travel restrictions and their timing of implementation. The model predicts that the demand for total beds and ICU beds will exceed the current U.S. capacity during the peak of the epidemic, projected for the second week of April. Information is integrated into a platform that is expected to update regularly and refine projections over time.

An important consideration is that if social distancing is successful in decreasing community transmission, the population may remain largely unexposed and thus susceptible to subsequent waves of infection.

2. Kissler et al. (Harvard T.H. Chan School of Public Health - Center for Communicable Disease Dynamics, US), examined the potential impact of social distance measures on transmission of COVID-19 infection in the U.S. Models covered a number of scenarios, including seasonal changes in transmission, and various reductions in transmission attained through social distancing and across different durations (4, 8, 12 and 20 weeks). The models used existing U.S. critical care beds capacity as benchmark. Models considered March 11, 2020 as the start date with social distancing measures implemented 2 weeks afterwards. According to this study, without interventions, or with modest effectiveness of social distancing interventions, the U.S. critical care surge capacity would be overwhelmed. Only intense measures would reduce this risk. The models also indicate that with social distancing interventions intense enough to prevent exceeding the critical care surge capacity, population exposure would be reduced. Thus, with most of the population still susceptible, resurgence of disease is likely after social distancing interventions are removed. Intermittent social distancing interventions are explored as alternatives.

3. Ferguson et al. (Imperial College, UK), modeled the potential effectiveness of multiple interventions in the U.K. and U.S. Interventions included case isolation at home (assumed ~70% compliance), voluntary home quarantine for asymptomatic cases (~50% compliance), social distancing of persons age 70 or older (~75% compliance), generalized social distancing (social contacts outside of households reduced by 75%, but household contacts increased by 25%), and closure of

schools and universities (household contacts increase by 50%, contacts in community increase by 25%).

Investigators used census data, including available household information and critical care bed surge capacity estimates. Models were calibrated to U.K. and U.S. situations starting on March 14, 2020. Without intervention, investigators estimated the peak in mortality would be approximately ~3 months from March 14, 2020; critical care surge bed capacity will be exceeded by mid-April. The only viable alternative would be to aggressively suppress transmission through a combination of case isolation, generalized social distancing and either household quarantine or school closures, starting one month after the start date. Effective interventions that reduce transmission would also limit the development of population immunity. Thus, it was anticipated that large subsequent waves of infections would be observed, and periodic interventions would be needed to prevent overwhelming the healthcare system.

4. Ruoran et al. (Harvard T.H. Chan School of Public Health - Center for Communicable Disease Dynamics, US), estimated hospital and ICU care needs in the U.S. based on observations from Wuhan and Guangzhou, China, from January 10, 2020 to February 29, 2020. In the U.S., after accounting for age differences and presence of comorbidities (using hypertension as proxy), a Wuhan-like outbreak would result in 21-49 per 100,000 people (age ≥ 15 years) requiring critical care per day during the epidemic peak. Importantly, assessment of U.S. cities showed Nashville may be at risk for a shortage of critical care resources. Overall, Ruoran et al. suggested that a Wuhan-like outbreak in the U.S. may substantially exceed current critical bed surge capacity. This was likely even after layering multiple interventions for pandemic mitigation. According to data from a 2010 article referenced in the study, there are 28 critical-care hospital beds for every 100,000 American adults. More recent surge capacity data are available but not referenced.

5. Hellewell et al. (London School of Hygiene and Tropical Medicine, UK), examined the projected effectiveness of case isolation and contact tracing using synthetic data. The study reports that, in early stages, approximately 80% of symptomatic contacts must be traced and isolated to control over 80% of outbreaks in the model, where control was defined as having no new infections 12 - 16 weeks after the initial cases. The study supports the finding that contact tracing and isolation of cases can be effective in controlling outbreaks. Effectiveness will be lower with intense transmission, more asymptomatic spread, and inability to identify cases and contacts in a timely manner. As suggested by other studies, multiple interventions will be required for effective control.

6. Kucharski et al. (London School of Hygiene and Tropical Medicine, UK), characterized early dynamics of viral transmission in Wuhan, China. The authors reported that transmissibility varied during the observation period, with a substantial decline following the implementation of strict control measures (implemented January 23, 2020).

The study suggests that intense travel restrictions and community interventions, including forced quarantine of cases and contacts and intense social distancing measures modified, but did not stop transmission. Multiple interventions would be needed to mitigate pandemic impact.

7. Wang et al. (Huazhong University, China), characterized early dynamics of disease transmission in Wuhan, China. Investigators used laboratory confirmed cases from the Municipal Notifiable Disease Reporting System, and incorporated the implementation of multiple interventions: travel restrictions, case isolation and quarantine, and generalized social distancing measures (beginning January 23, 2020) and centralized quarantine and treatment (beginning February 2, 2020). Models demonstrated that transmissibility was reduced after implementation of travel restrictions and strict

population control measures. This study indicates that intense travel restrictions and community social-distancing interventions including forced isolation and quarantine of cases and contacts, and intense social distancing including centralized quarantine can modify transmission parameters. Multiple interventions would be likely needed to mitigate the impact of the pandemic.

8. He et al. (Guangzhou Medical University, China - University of Hong Kong, China), characterized the role of asymptomatic virus shedding before disease onset on transmission using longitudinal data collected from throat swabs of patients in China. Substantial shedding was documented 2-3 days before disease onset, indicating transmission potential and emphasizing that contact tracing efforts should consider infectious periods prior to disease onset. Additionally, enhanced personal hygiene and social distancing measures will be important for transmission control.

Notes: Strategies for combating the spread of COVID-19 and their likely effectiveness, a review of models for forecasting the spread and severity of COVID-19, and other topics will be the subject of additional working papers. The views expressed are those of the advisory group and do not necessarily reflect the views of Vanderbilt University School of Medicine or Vanderbilt University Medical Center. Please see vumc.org/health-policy/covid-19-advisory-memos for those papers.