COVID-19 Maryland Hospital Impact
Eili Klein
Associate Professor, Johns Hopkins
Department of Emergency Medicine
Senior Fellow, Center for Disease Dynamics, Economics & Policy
May 12, 2021
Disclaimer

• These are unpublished preliminary results of a fast moving epidemic with many uncertain parameters. All results are subject to change
• The work was funded by the Centers for Disease Control, Modeling in Infectious Disease (MInD) Network
• Computational assistance provided by CCDC U.S. Army Research Laboratory and The National Center for Supercomputing Applications (NCSA)
• No other disclosures
First Disease Model
1911

Malaria

\[ S \xrightarrow{h} I \]

Life Cycle of the Malaria Parasite

1. Transmission to human (organs, gametocytes via bite)
2. Parasites enter liver and form merozoites
3. Sexual cycle (peripheral blood smears)
4. Liver cells rupture and merozoites released
5. Transmission to mosquito (organs, gametocytes via bite)
6. Malaria through red/white blood cells
7. Gametocytes develop, undergo meiosis
8. Malaria through red/white blood cells

\[ \text{# Bites, per Human per Day} \]

\[ \text{% of Bites that Infect Mosquitoes} \]

\[ \text{# Human Bites per Mosquito over its lifetime} \]
“Simple” model of infection assumes individuals are like molecules in a glass of water. Susceptible individuals become infected when the “bump into” already infected individuals.
SIR Model

Measles is a nearly perfect example of an SIR modeled disease

https://plus.maths.org/content/mathematics-diseases
Progression of population can be described by a set of ordinary differential equations where:

- \( \frac{dS}{dt} = -\beta SI \)
- \( \frac{dI}{dt} = \beta SI - \gamma I \)
- \( \frac{dR}{dt} = \gamma I \)

- \( \beta \) is the effective transmission rate
- \( \gamma \) is the rate the individuals recover
SIR Model

\[
\frac{dS}{dt} = -\beta SI \\
\frac{dI}{dt} = \beta SI - \gamma I \\
\frac{dR}{dt} = \gamma I
\]
What are models good for?

“All models are wrong … but some are useful” — George Box
Basic Reproductive Number ($R_0$)

- Susceptible $\rightarrow \beta$ Infected $\rightarrow \gamma$ Removed

\[
\frac{dS}{dt} = -\beta SI \\
\frac{dI}{dt} = \beta SI - \gamma I \\
\frac{dR}{dt} = \gamma I
\]

Can be rearranged to show that infections can only be increasing when

\[
\frac{\beta S_0}{\gamma} > 1
\]
Effective Reproductive Number (R)

Since the infection depletes the pool of susceptibles, the effective reproductive number drops in line with the proportion of susceptibles in the population (S), i.e. $R = R_0 S$.

When $R < 1$, the number of infected cases starts to fall and the epidemic dies out (i.e., herd immunity).
Why does R0 matter?

Drives dynamics and can aid in understanding concepts, such as how many people need to be vaccinated to stop transmission …
Why does R0 matter?

Drives dynamics and can aid in understanding concepts, such as how many people need to be vaccinated to stop transmission …
Why does R0 matter?

Drives dynamics and can aid in understanding concepts, such as how many people need to be vaccinated to stop transmission … but the same R₀ can produce different dynamics depending on transmission/recovery.

- Smallpox, R₀=5, p=80%
- Polio, R₀=7, p=85%
- Measles, R₀=15, p=95%
- Influenza, R₀=2, p=50%
- COVID-19, R₀=3-4

Changes in R0:
- R₀=2.5 End of May
- R₀=2.5 Mid-July
- R₀=2

Same R0, different assumptions about transmission and recovery.
R0 and SARS-CoV-2

• Heterogeneity in transmission

Infected individuals have an incubation period and then a period of infectiousness.

SARS

Influenza

Uncertainty remains about SARS-CoV-2 infectiousness pattern.
R0 and SARS-CoV-2

- Heterogeneity in transmission
- Superspreader events
- How to model?

20% of cases were responsible for 80% of local transmission

Traced spread of SARS-CoV-2 cases in Hong Kong: DOI: 10.21203/rs.3.rs-29548/v1
Model Structure

- **Individual Agent Model of Maryland**
  - All Maryland zip codes
  - Includes surrounding zip codes with patients that visit MD hospitals
- **Individuals are assumed to live in households and are spread across the state based on zip code level Census data**
  - Total population is ~9 million in 500+ zip codes
Model Assumptions

- Initial infections first arrived in Maryland in early to mid-February
- Continual seeding of infections is assumed to occur based on population size assuming largest zip codes more likely to get initial infections
- Contacts between non-household members are based on distance and population size of each zip code
Model Assumptions

- Contact and Transmission depends on type of contact and with whom contact is made
  - Individuals have highly variable contact patterns by age
    - Gamma distributed with kids having higher rates of contact
    - Age-related assortative contact patterns

Contact Rates by Age

Age Assortative Contact
Hospital Aggregations

Patients in general visit hospitals near them, particularly for emergency visits. More hospitals in an area spread out case load

- We based likelihood of patients visiting a hospital based on average wintertime visits for respiratory viruses
Patient Movement

Changes in movement based on mobile phone data

Patterns have been different depending on the county

Humidity has been shown to be related to transmission and infectivity in influenza. Evidence for COVID-19 is still emerging, but all respiratory viruses decrease in the summer when humidity increases and increase again when humidity falls in the winter.

Data from Guinea Pigs, suggests that transmission increases as humidity falls.

Viruses may also survive longer in lower humidity conditions.

Humidity data in 2020/1 similar to prior years.
Combining patient movement and humidity we derive an estimate of the transmission rate fit to the epidemic to this point and then forecast how this is likely to change based on future weather and behavior patterns.
Current Data in Maryland

Cases have continued to decline, now at ~11.5 cases per 100K. Positivity has plateaued a bit, but that may be because testing has fallen.
Case Geography

Zip codes with high case rates continued to be concentrated in Baltimore City/County region though rates have fallen recently.

Average cases per 100,000 residents last seven days by Zip code, 5/5/2021 to 5/12/2021

* Excludes zip codes with <10,000 residents
Statewide, daily hospitalizations and occupancy have fallen rapidly as expected.

As noted two weeks ago, the falling case rates and positivity rates predicted the fall in hospitalizations. Given continued declines in these metrics, hospitalization numbers should continue to fall.
Current Data at JHHS:
Symptomatic Positivity Rate

The symptomatic rate was a leading indicator of the Fall surge, and the rising rates in March were again the leading indicator of a surge in cases and hospitalizations. This continues to fall, suggesting there is limited risk of rising cases/hospitalizations in the near term, and that cases and hospitalizations should continue to fall in the next few weeks.
Given that the majority of cases are in the City, the COVID+ population has persisted at JHH, but overall appears to be starting to fall across the system.
Prior Forecasts

Estimates from August forecast the peak, but did not account for vaccination.
Model Inputs: Vaccination

We assume that a low, baseline, and high percentage of eligible individuals (>12 should be approved soon) refuse to get vaccinated by the end of June.

In addition we assess different vaccination paces in the short term. The big difference though is the total percentage of people vaccinated by September, which is assumed to range from a low of 60% to a high of 83%.
For the last month the data has accorded with the most optimistic scenarios, with hospitalizations falling below 1000 by early May. Uncertainty around the impact of reopening as well as how quickly absolute humidity may increase (as spring in Baltimore can be variable) led to a more conservative medium term estimate, but all signs pointed toward dramatic falloffs, either optimistically by late May or with a minor surge as society re-opened, later in June.
Current scenario projections are all similar in the short-term (so only a single scenario is shown). Faster/Slower reopening has only relatively minor impacts on the projected epidemic values between now and the end of June. The vast majority of the uncertainty relates to humidity expectations and uncertainty around the underlying transmission rate.

The most optimistic of the runs has hospitalizations falling below 500 by early June while the more moderate result suggests the end of June.
Herd Immunity?

As of 5/6/21 there have been 451,267 confirmed cases in Maryland. Assuming that testing is only capturing ~50% of cases (and slightly higher in March-May) that results in an estimated 961,514 cases or ~16% of population.

Current reported serology for the state is 16.8% (36,005 of 213,764)

- Approximately 3,125,612 with at least some protection (first shot).
- Depending on the percentage of individuals that have been both infected and vaccinated, total state immunity level is between 50-60%
Forecasts into the Fall/Winter

Can the virus come back?

Baseline

Low

High

Total Beds Needed for COVID-19 Patients
Contact Information

Eili Y. Klein
Department of Emergency Medicine
Johns Hopkins School of Medicine
5801 Smith Ave., Davis Suite 3220
Baltimore, MD 21209
eklein@jhu.edu
410-735-7559