About Us

• Biocomplexity Institute at the University of Virginia
  • Using big data and simulations to understand massively interactive systems and solve societal problems
• Over 20 years of crafting and analyzing infectious disease models
  • Pandemic response for Influenza, Ebola, Zika, and others

Points of Contact

Bryan Lewis
brylew@virginia.edu

Srini Venkatramanan
srini@virginia.edu

Madhav Marathe
marathe@virginia.edu

Chris Barrett
ChrisBarrett@virginia.edu

Biocomplexity COVID-19 Response Team

Aniruddha Adiga, Abhijn Adiga, Hannah Baek, Chris Barrett, Golda Barrow, Richard Beckman, Parantapa Bhattacharya, Andrei Bura, Jiangzhao Chen, Clark Cucinell, Patrick Corbett, Allan Dickerman, Stephen Eubank, Arindam Fadikar, Joshua Goldstein, Stefan Hoops, Ben Hurt, Sallie Keller, Ron Kenyon, Brian Klahn, Gizem Korkmaz, Vicki Lancaster, Bryan Lewis, Dustin Machi, Chunhong Mao, Acala Marathe, Madhav Marathe, Fanchao Meng, Henning Mortveit, Mark Orr, Joseph Outten, Akhil Peddireddy, Przemyslaw Porebski, SS Ravi, Erin Raymond, Jose Bayoan Santiago Calderon, James Schlitt, Aaron Schroeder, Stephanie Shipp, Samarth Swarup, Alex Telionis, Srinivasan Venkatramanan, Anil Vullikanti, James Walke, Amanda Wilson, Dawen Xie
Overview

• **Goal:** Understand impact of COVID-19 mitigations in Virginia

• **Approach:**
  • Calibrate explanatory mechanistic model to observed cases
  • Project infections for next 4 months
  • Consider a range of possible mitigation effects in "what-if" scenarios

• **Outcomes:**
  • Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
  • Geographic spread over time, case counts, healthcare burdens
Key Takeaways

Projecting future cases precisely is impossible and unnecessary. Even without perfect projections, we can confidently draw conclusions:

• **Case growth in Virginia speeds up, recording highest case rates of epidemic**
  
  • VA mean weekly incidence (28/100K) slightly up (from 27) as national surge finally slows a little (to 53/100K from 63/100K).
  
  • Reporting delays and overall testing decreases may impact projections, which are mostly up, showing potential for strain on health care system in some regions as early as December.

• Recent updates:
  
  • Ensemble of statistical and Machine Learning models integrated with Adaptive to guide projections
  
  • Extending projection trend window to 3 weeks to counter holiday effects
  
  • Planning scenarios pushed to Dec 10th and case ascertainment rates remain as updated in previous weeks

• The situation is changing rapidly. Models will be updated regularly.
Situation Assessment
Case Rate (per 100k) by VDH District

Surging Rates continue

- Majority of Districts have increasing rates
- Many districts experiencing highest rates of pandemic
- Some Districts remain steady or decreasing
Test Positivity by VDH District

Weekly changes in test positivity by district

- Increasing levels in many districts throughout the commonwealth
- More counties reporting over 10%

County level test positivity rates for RT-PCR tests.

- **Green**: Test positivity <5.0% (or with <20 tests in past 14 days)
- **Yellow**: Test positivity 5.0%-10.0% (or with <500 tests and <2000 tests/100k and >10% positivity over 14 days)
- **Red**: >10.0% and not meeting the criteria for “Green” or “Yellow”

https://data.cms.gov/stories/s/q5r5-gjyu
**District Trajectories**

**Goal:** Define epochs of a Health District’s COVID-19 incidence to characterize the current trajectory

**Method:** Find recent peak and use hockey stick fit to find inflection point afterwards, then use this period’s slope to define the trajectory

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Description</th>
<th>Weekly Case Rate (per 100K) bounds</th>
<th># Districts (prev weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declining</td>
<td>Sustained decreases following a recent peak</td>
<td>below -0.9</td>
<td>2 (1, 4)</td>
</tr>
<tr>
<td>Plateau</td>
<td>Steady level with minimal trend up or down</td>
<td>above -0.9 and below 0.5</td>
<td>3 (2, 4)</td>
</tr>
<tr>
<td>Slow Growth</td>
<td>Sustained growth not rapid enough to be considered a Surge</td>
<td>above 0.5 and below 2.5</td>
<td>9 (19, 19)</td>
</tr>
<tr>
<td>In Surge</td>
<td>Currently experiencing sustained rapid and significant growth</td>
<td>2.5 or greater</td>
<td>21 (13, 8)</td>
</tr>
</tbody>
</table>
District Trajectories

### Status

<table>
<thead>
<tr>
<th>Status</th>
<th># Districts (prev weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declining</td>
<td>2 (1, 4)</td>
</tr>
<tr>
<td>Plateau</td>
<td>3 (2, 4)</td>
</tr>
<tr>
<td>Slow Growth</td>
<td>9 (19, 19)</td>
</tr>
<tr>
<td>In Surge</td>
<td>21 (13, 8)</td>
</tr>
</tbody>
</table>

Curve shows smoothed case rate (per 100K)
Trajectories of states in label & chart box
Case Rate curve colored by Reproductive
Estimating Daily Reproductive Number

Nov 30th Estimates

<table>
<thead>
<tr>
<th>Region</th>
<th>Date Confirmed $R_e$</th>
<th>Date Confirmed Diff Last Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>State-wide</td>
<td>1.120</td>
<td>-0.286</td>
</tr>
<tr>
<td>Central</td>
<td>1.041</td>
<td>-0.339</td>
</tr>
<tr>
<td>Eastern</td>
<td>1.104</td>
<td>-0.385</td>
</tr>
<tr>
<td>Far SW</td>
<td>1.075</td>
<td>0.057</td>
</tr>
<tr>
<td>Near SW</td>
<td>0.957</td>
<td>-0.659</td>
</tr>
<tr>
<td>Northern</td>
<td>1.266</td>
<td>-0.105</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.119</td>
<td>-0.346</td>
</tr>
</tbody>
</table>

Methodology

- Wallinga-Teunis method (EpiEstim$^3$) for cases by confirmation date
- Serial interval: 6 days (2 day std dev)
- Using Confirmation date since due to increasingly unstable estimates from onset date due to backfill

Changes in Case Detection

<table>
<thead>
<tr>
<th>Timeframe (weeks)</th>
<th>Mean days</th>
<th>% difference from overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>April (13-16)</td>
<td>8.5</td>
<td>51%</td>
</tr>
<tr>
<td>May (17-21)</td>
<td>5.6</td>
<td>0%</td>
</tr>
<tr>
<td>June (22-25)</td>
<td>6.0</td>
<td>6%</td>
</tr>
<tr>
<td>July (26-30)</td>
<td>6.3</td>
<td>12%</td>
</tr>
<tr>
<td>Aug (31-34)</td>
<td>4.9</td>
<td>-14%</td>
</tr>
<tr>
<td>Sept (35-38)</td>
<td>4.4</td>
<td>-22%</td>
</tr>
<tr>
<td>Oct (39-43)</td>
<td>4.3</td>
<td>-25%</td>
</tr>
<tr>
<td>Nov (44-46)</td>
<td>4.2</td>
<td>-25%</td>
</tr>
<tr>
<td>Overall (13-46)</td>
<td>5.6</td>
<td>0%</td>
</tr>
</tbody>
</table>

Testing levels have dipped during the holiday week.

Positive shows a sharp rise in last couple weeks.

Days from Onset to Diagnosis and Test Positivity - Weekly

Number of Testing Encounters by Lab Report
Date - All Health Districts, PCR Only

Accessed 8:30am December 2, 2020
https://www.vdh.virginia.gov/coronavirus/
Mask usage in Virginia

State level mask usage as reported via Facebook surveys over the past month shows ranges from 83% to 89%

- Relatively stable over time
- Limited variance across the commonwealth
- ~3000 daily responses from VA

Data Source: [https://covidcast.cmu.edu](https://covidcast.cmu.edu)

Some county level fluctuations since beginning of Sept., though data quality may be affected by sample sizes.

Correlations seen at national level with mask use and case rate start to emerge across VA counties, due to surging growth and more limited survey results due to election.
Race and Ethnicity Attack Rates (per 100K)

Cumulative Race and Ethnicity Attack Rates (per 100k)

- Black and Latinx populations have much higher case, hospitalization, and death rates
- Disparity is more pronounced in some districts than others
- Based on 2019 census race-ethnicity data by county
Race and Ethnicity cases per 100K

Rates per 100K of each Racial-Ethnic population by Health District
- Each Health District’s Racial-Ethnic population is plotted by their Hospitalization and Case Rate
- Points are sized based on their overall population size
- Overlapping labels removed for clarity

2-Dec-20
Impact across Density and Income

All zip codes show rapid growth, with 4th quintile (60-80th percentile) now bearing the highest rate.

Full evolution of pandemic, shows shifts from denser and wealthier zip codes to poorer and less dense zip codes, followed by a repeat of the pattern. Recently see an uptick across the spectrum of density and income.
Other State Comparisons

**Trajectories of States**

- VA and most of mid-Atlantic states are in surge (37 total in US)
- TN and SC showing some slowing, other have minor deviations which may be related reporting artifacts from the holiday

**Tests per Day and Test Positivity**

- VA’s test positivity rate continues to rise with many of its neighbors
- Testing volumes have increased for many with recent disruption from the holiday
As weather cools and humidity drops, SARS-CoV2 survival and chance of transmission may rise.

Correlations with other factors are also strong for R (0, 7, 14 day delay) and confirmed cases (7 and 14 day delay).

Weather variables better correlation with R estimates, while mobility and mask usage correlate well with case rates.
Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Concentrations of very high prevalence in many zip codes
- Several of the top ten zip codes are home to prisons
- Southwest has considerable concentration of high prevalence zips
- Some counts are low and suppressed to protect anonymity, those are shown in white
Risk of Exposure by Group Size

Case Prevalence in the last week by zip code used to calculate risk of encountering someone infected in a gathering of randomly selected people (group size 25 or 50)

- Assumes 3 undetected infections per confirmed case (ascertainment rate from recent seroprevalence survey)
- Moderate risk for groups of 50 across the commonwealth, especially in the southern half of the state
- Some zip codes have high likelihood of exposure even in groups of 25
Risk of Exposure in Groups of 50

Northwest

Far Southwest

Near Southwest

Eastern

Central

University of Virginia

BIOCOMPLEXITY INSTITUTE
Zip Code Hot Spots

Hotspots across commonwealth

- More spread out but remain concentrated in the Southwest
- Captures some very high prevalence rates in some zips
Model Update – Adaptive Fitting
Adaptive Fitting Approach

Each county fit precisely, with recent trends used for future projection

- Allows history to be precisely captured, and used to guide bounds on projections

Model: An alternative use of the same meta-population model, PatchSim

- Allows for future “what-if” Scenarios to be layered on top of calibrated model
- Eliminates connectivity between patches, to allow calibration to capture the increasingly unsynchronized epidemic

External Seeding: Steady low-level importation

- Widespread pandemic eliminates sensitivity to initial conditions
- Uses steady 1 case per 10M population per day external seeding

Fairfax County

- Steady low-level importation
- Widespread pandemic eliminates sensitivity to initial conditions
- Uses steady 1 case per 10M population per day external seeding
Using Ensemble Model to Guide Projections

An ensemble methodology that combines the Adaptive Fitting and machine learning and statistical models has been developed and refined

- **Models**: Adaptive Fitting, ARIMA, LSTM, AR, spatially driven AR, Kalman Filters (ENKF)
- This approach facilitates the use of other data streams (weather, mobility, etc.)
- Ensemble provides scaffolding for the Adaptive Fitting’s short-term projections
Seroprevalence updates to model design

Several seroprevalence studies provide better picture of how many actual infections have occurred

- Virginia Serology Study estimated 2.4% of Virginians estimated infected (as of Aug 15th)
- CDC Nationwide Commercial Laboratory Seroprevalence Survey estimated 3.9% [1.7% – 7.1%] seroprevalence as of Aug 15th (Updates recently released, similar and will be included next week)

These findings are equivalent to an ascertainment ratio of ~3x, with bounds of (1x to 7x)

- Thus for 3x there are 3 total infections in the population for every confirmed case
- Uncertainty design has been shifted to these bounds (previously higher ascertainment as was consistent earlier in the pandemic were being used)
Calibration Approach

**Data:**
- County level case counts by date of onset (from VDH)
- Confirmed cases for model fitting

**Calibration:** fit model to observed data and ensemble’s forecast
- Tune transmissibility across ranges of:
  - Duration of incubation (5-9 days), infectiousness (3-7 days)
  - Undocumented case rate (1x to 7x) guided by seroprevalence studies
  - Detection delay: exposure to confirmation (4-12 days)
- Approach captures uncertainty, but allows model to precisely track the full trajectory of the outbreak

**Project:** future cases and outcomes generated using the collection of fit models run into the future
- Mean trend from last 14 days of observed cases and first week of ensemble’s forecast used
- Outliers removed based on variances in the previous 3 weeks
- 2 week interpolation to smooth transitions in rapidly changing trajectories
Scenarios – Seasonal Effects

- Societal changes in the past month have led to an increase in transmission rates, these could continue to drive transmission
  - Seasonal impact of weather patterns
  - More interactions at places of learning
  - Travel related to holidays and traditional large family gatherings
  - Fatigue with infection control practices

- Population’s behaviors determine the level of control of transmission we can achieve

- Three scenarios capture possible trajectories starting Dec 10th, 2020
  - Adaptive: No change from base projection
  - Adaptive-MoreControl: 15% decrease in transmission starting Dec 10th, 2020
  - Adaptive-LessControl: 15% increase in transmission starting Dec 10th, 2020
Model Results
Outcome Projections

Confirmed cases
Virginia Daily Confirmed - Comparison

Estimated Hospital Occupancy

Daily Deaths
Virginia Daily Death - Comparison

Cumulative Confirmed cases
Virginia Cumulative Confirmed - Comparison

2-Dec-20
District Level Projections: Adaptive

Adaptive projections by District

• Projections that best fit recent trends
• Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario
District Level Projections: Adaptive-MoreControl

Adaptive projections by District

- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario
Adaptive projections by District

- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario
Hospital Demand and Bed Capacity by Region

Capacities* by Region – Adaptive-LessControl
COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds

If Adaptive-LessControl scenario persists:
• All regions approach initial bed capacity this winter
• Over capacity may occur in Northern (early January); Eastern (late January).

* Assumes average length of stay of 8 days

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>Adaptive</th>
<th>Adaptive-LessControl</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/22/20</td>
<td>13,257</td>
<td>13,257</td>
</tr>
<tr>
<td>11/29/20</td>
<td>17,448</td>
<td>17,447</td>
</tr>
<tr>
<td>12/06/20</td>
<td>20,416</td>
<td>20,412</td>
</tr>
<tr>
<td>12/13/20</td>
<td>23,381</td>
<td>23,376</td>
</tr>
<tr>
<td>12/20/20</td>
<td>26,600</td>
<td>28,471</td>
</tr>
<tr>
<td>12/27/20</td>
<td>30,580</td>
<td>36,851</td>
</tr>
<tr>
<td>1/3/20</td>
<td>34,724</td>
<td>45,471</td>
</tr>
<tr>
<td>1/10/20</td>
<td>38,742</td>
<td>54,750</td>
</tr>
<tr>
<td>1/17/20</td>
<td>42,348</td>
<td>63,417</td>
</tr>
<tr>
<td>1/24/20</td>
<td>44,973</td>
<td>70,537</td>
</tr>
<tr>
<td>1/31/20</td>
<td>46,666</td>
<td>75,282</td>
</tr>
<tr>
<td>2/7/20</td>
<td>47,238</td>
<td>77,159</td>
</tr>
</tbody>
</table>
Key Takeaways

Projecting future cases precisely is impossible and unnecessary. Even without perfect projections, we can confidently draw conclusions:

• **Case growth in Virginia speeds up, recording highest case rates of epidemic**

• VA mean weekly incidence (28/100K) slightly up (from 27) as national surge finally slows a little (to 53/100K from 63/100K).

• Reporting delays and overall testing decreases may impact projections, which are mostly up, showing potential for strain on health care system in some regions as early as December.

• Recent updates:
  • Ensemble of statistical and Machine Learning models integrated with Adaptive to guide projections
  • Extending projection trend window to 3 weeks to counter holiday effects
  • Planning scenarios pushed to Dec 10th and case ascertainment rates remain as updated in previous weeks

• The situation is changing rapidly. Models will be updated regularly.
References


Google. COVID-19 community mobility reports. [https://www.google.com/covid19/mobility/](https://www.google.com/covid19/mobility/)

Questions?

Biocomplexity COVID-19 Response Team

Aniruddha Adiga, Abhijin Adiga, Hannah Baek, Chris Barrett, Golda Barrow, Richard Beckman, Parantapa Bhattacharya, Andrei Bura, Jiangzhuo Chen, Patrick Corbett, Clark Cucinell, Allan Dickerman, Stephen Eubank, Arindam Fadikar, Joshua Goldstein, Stefan Hoops, Ben Hurt, Sallie Keller, Ron Kenyon, Brian Klahn, Gizem Korkmaz, Vicki Lancaster, Bryan Lewis, Dustin Machi, Chunhong Mao, Achla Marathe, Madhav Marathe, Fanchao Meng, Henning Mortveit, Mark Orr, Joseph Outten, Akhil Peddireddy, Przemyslaw Porebski, SS Ravi, Erin Raymond, Jose Bayoan Santiago Calderon, James Schlitt, Aaron Schroeder, Stephanie Shipp, Samarth Swarup, Alex Telionis, Srinivasan Venkatramanan, Anil Vullikanti, James Walke, Amanda Wilson, Dawen Xie

Points of Contact

Bryan Lewis
brylew@virginia.edu

Srini Venkatramanan
srini@virginia.edu

Madhav Marathe
marathe@virginia.edu

Chris Barrett
ChrisBarrett@virginia.edu
Supplemental Slides
Estimating Daily Reproductive Number

Nov 30th Estimates

<table>
<thead>
<tr>
<th>Region</th>
<th>Date of Onset Re</th>
<th>Date Onset Diff Last Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>State-wide</td>
<td>1.030</td>
<td>-0.222</td>
</tr>
<tr>
<td>Central</td>
<td>0.963</td>
<td>-0.264</td>
</tr>
<tr>
<td>Eastern</td>
<td>1.121</td>
<td>-0.188</td>
</tr>
<tr>
<td>Far SW</td>
<td>0.908</td>
<td>-0.166</td>
</tr>
<tr>
<td>Near SW</td>
<td>0.922</td>
<td>-0.311</td>
</tr>
<tr>
<td>Northern</td>
<td>1.069</td>
<td>-0.207</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.135</td>
<td>-0.205</td>
</tr>
</tbody>
</table>

Methodology

- Wallinga-Teunis method (EpiEstim\(^1\)) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

Estimating Daily Reproductive Number

<table>
<thead>
<tr>
<th>Region</th>
<th>Date of Onset $R_e$</th>
<th>Confirmed Date $R_e$</th>
<th>Range of $R_e$</th>
<th>Onset Diff Last Week</th>
<th>Confirmed Diff Last Week</th>
<th>Range of Diff from Last Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>State-wide</td>
<td>1.030</td>
<td>1.234</td>
<td>[1.03-1.234]</td>
<td>-0.222</td>
<td>0.143</td>
<td>[-0.22 to 0.14]</td>
</tr>
<tr>
<td>Central</td>
<td>0.963</td>
<td>1.064</td>
<td>[0.963-1.064]</td>
<td>-0.264</td>
<td>-0.035</td>
<td>[-0.26 to -0.03]</td>
</tr>
<tr>
<td>Eastern</td>
<td>1.121</td>
<td>1.369</td>
<td>[1.121-1.369]</td>
<td>-0.188</td>
<td>0.332</td>
<td>[-0.19 to 0.33]</td>
</tr>
<tr>
<td>Far SW</td>
<td>0.908</td>
<td>1.022</td>
<td>[0.908-1.022]</td>
<td>-0.166</td>
<td>-0.204</td>
<td>[-0.17 to -0.2]</td>
</tr>
<tr>
<td>Near SW</td>
<td>0.922</td>
<td>1.225</td>
<td>[0.922-1.225]</td>
<td>-0.311</td>
<td>0.307</td>
<td>[-0.31 to 0.31]</td>
</tr>
<tr>
<td>Northern</td>
<td>1.069</td>
<td>1.280</td>
<td>[1.069-1.28]</td>
<td>-0.207</td>
<td>0.125</td>
<td>[-0.21 to 0.12]</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.135</td>
<td>1.399</td>
<td>[1.135-1.399]</td>
<td>-0.205</td>
<td>0.192</td>
<td>[-0.21 to 0.19]</td>
</tr>
</tbody>
</table>

Methodology
- Wallinga-Teunis method (EpiEstim$^1$) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

Mask usage sample sizes
Test positivity across VA counties

- CMS weekly summary (used for guiding nursing homes testing protocol)
- Data: COVID-19 Electronic Lab Reporting (CELR); HHS Unified Testing Dataset;
- County level testing counts and test positivity rates for RT-PCR tests.
  - **Green**: Test positivity <5.0% or with <20 tests in past 14 days
  - **Yellow**: Test positivity 5.0%-10.0% or with <500 tests and <2000 tests/100k and >10% positivity over 14 days
  - **Red**: >10.0% and not meeting the criteria for “Green” or “Yellow”

https://data.cms.gov/stories/s/q5r5-gjyu

Red on Oct 21 (4-week back)

Red on Nov 11 (latest)
Agent-based Model (ABM)

EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing

Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations
ABM Social Distancing Rebound Study Design

Study of "Stay Home" policy adherence

- Calibration to current state in epidemic
- Implement “release” of different proportions of people from "staying at home"

Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels
Medical Resource Demand Dashboard

https://nssac.bii.virginia.edu/covid-19/vmrddash/