Estimation of COVID-19 Impact in Virginia

December 22nd, 2020
(data current to December 19th – 21st)
Biocomplexity Institute Technical report: TR 2020-161

University of Virginia

biocomplexity.virginia.edu
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

**Biocomplexity COVID-19 Response Team**


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22-Dec-20
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 rate growth in Virginia slows and steadies with mixed patterns across commonwealth**
- **VA mean weekly incidence (43/100K) steady (from 44) as national surge slows and is slightly down for first week in months (to 59/100K from 66/100K).**
- Recent updates:
  - Preliminary estimates for vaccination impact
  - Planning scenarios remain on Christmas holiday, starting Dec 24th
- Behavioral changes can outpace impact of optimistic vaccine rollout and prevent significantly more cases by Spring
- The situation is changing rapidly. Models will be updated regularly.
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 with many districts above 10% for several weeks

• 101 counties reporting over 10% on Dec 9

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-giyu
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 week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declining</td>
<td>Sustained decreases following a recent peak</td>
<td>below -0.9</td>
<td>12 (2)</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 (1)</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>11 (7)</td>
</tr>
<tr>
<td>In Surge</td>
<td>Currently experiencing sustained rapid and significant growth</td>
<td>2.5 or greater</td>
<td>9 (25)</td>
</tr>
</tbody>
</table>
# District Trajectories

<table>
<thead>
<tr>
<th>Status</th>
<th># Districts (prev week)</th>
</tr>
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<tbody>
<tr>
<td>Declining</td>
<td>12 (2)</td>
</tr>
<tr>
<td>Plateau</td>
<td>3 (1)</td>
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<tr>
<td>Slow Growth</td>
<td>11 (7)</td>
</tr>
<tr>
<td>In Surge</td>
<td>9 (25)</td>
</tr>
</tbody>
</table>

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

22-Dec-20
Estimating Daily Reproductive Number

Dec 20th 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>0.924</td>
<td>-0.470</td>
</tr>
<tr>
<td>Central</td>
<td>0.918</td>
<td>-0.214</td>
</tr>
<tr>
<td>Eastern</td>
<td>1.139</td>
<td>-0.248</td>
</tr>
<tr>
<td>Far SW</td>
<td>0.945</td>
<td>-0.258</td>
</tr>
<tr>
<td>Near SW</td>
<td>0.848</td>
<td>-0.537</td>
</tr>
<tr>
<td>Northern</td>
<td>0.821</td>
<td>-0.436</td>
</tr>
<tr>
<td>Northwest</td>
<td>0.972</td>
<td>-0.250</td>
</tr>
</tbody>
</table>

Methodology

- Wallinga-Teunis method (EpiEstim) 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>8.3</td>
<td>51%</td>
</tr>
<tr>
<td>May (17-21)</td>
<td>5.6</td>
<td>2%</td>
</tr>
<tr>
<td>June (22-25)</td>
<td>5.9</td>
<td>7%</td>
</tr>
<tr>
<td>July (26-30)</td>
<td>6.4</td>
<td>16%</td>
</tr>
<tr>
<td>Aug (31-34)</td>
<td>4.8</td>
<td>-12%</td>
</tr>
<tr>
<td>Sept (35-38)</td>
<td>4.4</td>
<td>-20%</td>
</tr>
<tr>
<td>Oct (39-43)</td>
<td>4.3</td>
<td>-21%</td>
</tr>
<tr>
<td>Nov (44-47)</td>
<td>4.4</td>
<td>-21%</td>
</tr>
<tr>
<td>Overall (13-47)</td>
<td>5.5</td>
<td>0%</td>
</tr>
</tbody>
</table>

Test positivity vs. Onset to Diagnosis

- Test positivity remains high.
- July: 6.3 days
- Aug: 4.9 days
- Sept: 4.4 days
- Oct: 4.3 days
- Nov: 4.3 days

Testing levels have rebounded but are fluctuating.
State level mask usage as reported via Facebook surveys over the past month shows ranges from 83% to 91% 
• Relatively stable over time 
• Limited variance across the commonwealth 
• ~3000 daily responses from VA 

Data Source: https://covidcast.cmu.edu
Health Care Worker Prevalence (per 100K)

**Case Rates among health workers**

- Based on census counts of patient-facing health care workers (Practitioners and Technologists)
- Prevalence rate for week ending Dec 19
- Many areas have high burden on HCW, especially southern VA
Race and Ethnicity – Recent Rate Changes (per 100K)

Recent Changes in Race and Ethnicity Rates (per 100k)

- Two week change in population level rates
- Black, Latinx and 2 or more races populations have much higher changes in 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
All zip codes show similar slowing of growth, wealthiest zip codes drop the fastest.

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

- Many of the states with huge surges in past 6 weeks (Plains & Midwest) are subsiding

- VA slows its growth
- Many mid-Atlantic states remain in surge (20 total in US)
- Several neighbors have plateaued, though rates remain high
- All states have highest rates of the pandemic in past 2 weeks
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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Zip Code Name</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Craigsville *</td>
<td>24,670</td>
</tr>
<tr>
<td>2</td>
<td>Pocahontas *</td>
<td>18,880</td>
</tr>
<tr>
<td>3</td>
<td>Mitchells *</td>
<td>7,510</td>
</tr>
<tr>
<td>4</td>
<td>Burkeville *</td>
<td>5,410</td>
</tr>
<tr>
<td>5</td>
<td>Mathews</td>
<td>4,410</td>
</tr>
<tr>
<td>6</td>
<td>Bland *</td>
<td>4,150</td>
</tr>
<tr>
<td>7</td>
<td>Singers Glen</td>
<td>4,040</td>
</tr>
<tr>
<td>8</td>
<td>Honaker</td>
<td>3,900</td>
</tr>
<tr>
<td>9</td>
<td>Dillwyn *</td>
<td>3,380</td>
</tr>
<tr>
<td>10</td>
<td>Cleveland</td>
<td>3,010</td>
</tr>
</tbody>
</table>

* Denotes zip codes with state prisons.

Point Prevalence by Zip Code (2020-12-19)

Only includes zips with pop ≥ 1000 and no supp. data.

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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)

- Assumes 3 undetected infections per confirmed case (ascertainment rate from recent seroprevalence survey)
- On left, minimum size of a group with a 50% chance an individual is infected by zip code (eg in a group of 20 in Staunton, there is a 50% chance someone will be infected)
- Some zip codes have high likelihood of exposure even in groups of 25

1  24430 Craigsville  2  24655 Pocahontas
2  24430 Craigsville  3  22729 Mitchell
3  24655 Pocahontas  4  23922 Burkeville
4  22729 Mitchell  5  23109 Mathews
5  23922 Burkeville  6  23415 Bland
6  23109 Mathews  7  22850 Singers Glen
7  23415 Bland  8  24260 Honaker
8  22850 Singers Glen  9  23836 Dilley
9  24260 Honaker  10  24225 Clevelan
10  23836 Dilley

Only includes zip with pop > 1000 and no supp. data.
* Denotes zip codes with state prisons.

Group Size Needed for 50% Likelihood of ≥1 Infected

Based on zip code point prevalence for week ending 2020-12-19

Likelihood of ≥1 Infected Members (Group of 25)

Based on zip code point prevalence for week ending 2020-12-19

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New variant of SARS-CoV2 circulating in UK

Prevalence in the UK of variant with potentially increased transmissibility but no evidence of higher severity

• Aliases: Variant VUI 202012/01 and Lineage B.1.1.7

• No direct evidence of this variant in US yet, but recent genomic surveillance in US is limited, it is likely circulating

• This variant is still detected by PCR and is unlikely to alter efficacy of vaccines or other immune treatments

• Evolution expected when virus under selective pressure

• NERVTAG suggests that “VUI-202012/01 demonstrates a substantial increase in transmissibility compared to other variants”

• Mutations include but not limited to
  • (69 Y/-) Two deletions in the spike protein associated with immune evasion; (N501Y) Mutation in the receptor binding domain w/ higher binding affinity w/ ACE2; (P681H) Mutation in the S1/S2 furin cleavage site which promotes entry
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
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 4.1% [2.4% – 6.2%] seroprevalence as of Oct 9th-21st up from 3.2% a month earlier

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 ascentions as was consistent earlier in the pandemic were being used)

https://covid.cdc.gov/covid-data-tracker/#national-lab

Virginia Coronavirus Serology Project
Interim findings by region and statewide - July 22, 2020

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of participants</th>
<th>Number antibody positive</th>
<th>Crude prevalence per 100 participants</th>
<th>Weighted prevalence*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>400</td>
<td>8</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>East</td>
<td>707</td>
<td>9</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Northern</td>
<td>819</td>
<td>36</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Northwest</td>
<td>756</td>
<td>11</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Southwest</td>
<td>431</td>
<td>3</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Virginia</td>
<td>3,113</td>
<td>67</td>
<td>2.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*Weighted prevalence is reweighted by region, age, sex, race, ethnicity, and insurance status to match census population.

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

Accessed 10:00am December 22, 2020
https://www.vdh.virginia.gov/coronavirus/
Scenarios – Seasonal Effects and Vaccines

• 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, viral mutations, 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

• Vaccination has started, focus on priority groups may limit population level effects initially, though small impacts may be observed in early February
  • Initial rollout estimated at 12.5M people in US (~330K in VA) in January, then 25M (~660K) per month, assumes limited impact from any vaccinations in December.
  • Assume all available vaccine is administered and has 80% efficacy in 2 weeks (timing more sensitive than max efficacy in early stages)
  • Counterfactuals with no vaccine (“NoVax”) are provided for comparison purposes
Scenarios – Seasonal Effects and Vaccines

• Three behavioral scenarios capture possible trajectories starting Dec 24th, 2020
  • **Adaptive**: No change from base projection
  • **Adaptive-MoreControl**: 15% decrease in transmission starting Dec 24th, 2020
  • **Adaptive-LessControl**: 15% increase in transmission starting Dec 24th, 2020

• Vaccinations are incorporated in “base” projections, counterfactuals without vaccinations provide lower bound on vaccines impact
  • **Adaptive-NoVax**: No change from base projection without vaccine
  • **Adaptive-NoVax-MoreControl**: 15% decrease in transmission starting Dec 24th, 2020 without vaccine
  • **Adaptive-NoVax-LessControl**: 15% increase in transmission starting Dec 24th, 2020 without vaccine
Model Results
Outcome Projections

Confirmed cases
Virginia Daily Confirmed - Comparison

Confirmed cases

- Adaptive-NoVax-LessControl
- Adaptive-LessControl
- Adaptive-NoVax-MoreControl
- Adaptive-MoreControl
- Adaptive
- Adaptive-NoVax

Estimated Hospital Occupancy

Daily Deaths

Daily Deaths

Cumulative Confirmed cases

Cumulative Confirmed cases

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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
District Level Projections: Adaptive-LessControl

Adaptive projections by District

- Projections that best fit recent trends
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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
• Surge capacity exceeded in Northern region, in mid-Jan to early March

* 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>12/20/20</td>
<td>25,271</td>
<td>25,275</td>
</tr>
<tr>
<td>12/27/20</td>
<td>27,183</td>
<td>27,248</td>
</tr>
<tr>
<td>1/3/20</td>
<td>31,078</td>
<td>33,457</td>
</tr>
<tr>
<td>1/10/20</td>
<td>35,210</td>
<td>42,901</td>
</tr>
<tr>
<td>1/17/20</td>
<td>39,232</td>
<td>52,077</td>
</tr>
<tr>
<td>1/24/20</td>
<td>42,980</td>
<td>61,541</td>
</tr>
<tr>
<td>1/31/20</td>
<td>45,777</td>
<td>69,334</td>
</tr>
<tr>
<td>2/7/20</td>
<td>47,125</td>
<td>74,202</td>
</tr>
<tr>
<td>2/14/20</td>
<td>46,901</td>
<td>76,371</td>
</tr>
<tr>
<td>2/21/20</td>
<td>45,690</td>
<td>74,913</td>
</tr>
<tr>
<td>2/28/20</td>
<td>42,910</td>
<td>69,637</td>
</tr>
<tr>
<td>3/7/20</td>
<td>38,745</td>
<td>61,531</td>
</tr>
</tbody>
</table>

Weekly confirmed cases
Key Takeaways

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

- **Case rate growth in Virginia slows and steadies with mixed patterns across commonwealth**
- VA mean weekly incidence (43/100K) steady (from 44) as national surge slows and is slightly down for first week in months (to 59/100K from 66/100K).

- Recent updates:
  - Preliminary estimates for vaccination impact
  - Planning scenarios remain on Christmas holiday, Dec 24th

- Behavioral changes can outpace impact of optimistic vaccine rollout and prevent significantly more cases by Spring

- 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

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Estimating Daily Reproductive Number

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<th>Date of Onset</th>
<th>Date Onset Diff Last Week</th>
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<tbody>
<tr>
<td>State-wide</td>
<td>0.977</td>
<td>-0.275</td>
</tr>
<tr>
<td>Central</td>
<td>0.854</td>
<td>-0.491</td>
</tr>
<tr>
<td>Eastern</td>
<td>1.009</td>
<td>-0.176</td>
</tr>
<tr>
<td>Far SW</td>
<td>1.083</td>
<td>-0.323</td>
</tr>
<tr>
<td>Near SW</td>
<td>0.988</td>
<td>-0.301</td>
</tr>
<tr>
<td>Northern</td>
<td>0.949</td>
<td>-0.253</td>
</tr>
<tr>
<td>Northwest</td>
<td>1.054</td>
<td>-0.193</td>
</tr>
</tbody>
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Methodology

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


22-Dec-20
Mask usage sample sizes
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

**Synthetic Population**

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations

**Detailed Disease Course of COVID-19**

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