Estimation of COVID-19 Impact in Virginia

June 17\textsuperscript{th}, 2020
(data current to June 16\textsuperscript{th})

Biocomplexity Institute Technical report: TR 2020-075

biocomplexity.virginia.edu
Who We Are

• 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

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Biocomplexity COVID-19 Response Team

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Overview

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

• **Approach:**
  • Calibrate explanatory mechanistic model to observed cases
  • Project infections through the end of summer
  • 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:

• **We remain in a period of transition, shifting to sustaining control through test and trace and other mitigations rather than strict social distancing.**

• Model updates this week
  • Better calibrated to district level variations across the Commonwealth
  • Altered projection scenarios to capture increased mixing moderated with good infection control practices (decreased risk per interaction)
  • Additional analyses to inform restructuring of model for next phase of epidemic

• Impact of better detection and isolation are showing.

• The situation is changing rapidly. Models will be updated regularly.
Model Configuration and Data Analysis
Simulation Engine – PatchSim

- Metapopulation model
  - Represents each population and its interactions as a single patch
  - 133 patches for Virginia counties and independent cities
- Extended SEIR disease representation
  - Includes asymptomatic infections and treatments
- Mitigations affect both disease dynamics and population interactions
- Runs fast on high-performance computers
  - Ideal for calibration and optimization

Model Configuration

- **Transmission**: Parameters are calibrated to the observed case counts
  - Reproductive number: 2.1 - 2.3
  - Infectious period (time of infectiousness before full isolation): 3.3 to 5 days

- **Initial infections**: Start infections from confirmed cases by county
  - Timing and location based on onset of illness from VDH data
  - Assume 15% detection rate, so one confirmed case becomes ~7 initial infections

- **Mitigations**: Intensity of social distancing rebound and control sustaining mitigations into the future are unknowable, thus explored through 5 scenarios
Mitigation Scenarios: Rebound Intensity x Detection

Pause from Social Distancing: Began on March 15th
- Lifted on May 15th (61 days), with two-week delay (75 days) for select counties*
- **Intensity**: Social distancing pauses and significantly reduces case growth, this level varies by VDH Health District and is fit through an analysis of growth rate during the Pause

Intensity of Rebound:
- **Steady**: Intensity of effective mixing remains steady fromPause as infection control practices moderate increased interactions
- **Light**: Effective mixing returns to 1/6th of pre-pandemic levels
- **Full Rebound**: Interactions return completely (100%) to pre-pandemic levels, as a reference

Tracing and Isolation: Increased Testing Capacity coupled with infection control measures can limit the period of infectiousness without isolation
- **Better Detection**: Observed relative reductions in days from onset to diagnosis applied to infectious period and remain stable into future for projections

* Select counties as mentioned by recent releases from Governor Northam’s office
# Five Mitigation Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rebound Intensity</th>
<th>Better Detection</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light</td>
<td>No</td>
<td>Light</td>
<td>Light Rebound, Detection same</td>
</tr>
<tr>
<td>2</td>
<td>Steady</td>
<td>No</td>
<td>Steady</td>
<td>Steady Interactions, Detection same</td>
</tr>
<tr>
<td>3</td>
<td>Light</td>
<td>Yes</td>
<td>Light – Better Detection</td>
<td>Light Rebound, Detection improved</td>
</tr>
<tr>
<td>4</td>
<td>Steady</td>
<td>Yes</td>
<td>Steady – Better Detection</td>
<td>Steady Interactions, Detection improved</td>
</tr>
<tr>
<td>5</td>
<td>Full</td>
<td>No</td>
<td>Full Rebound</td>
<td>Return to No mitigation</td>
</tr>
</tbody>
</table>
# Full Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmission</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmissibility ($R_0$)</td>
<td>2.2 [2.1 – 2.3]</td>
<td>Reproductive number</td>
</tr>
<tr>
<td>Incubation period</td>
<td>5 days</td>
<td>Time from infection to infectious</td>
</tr>
<tr>
<td>Infectious period</td>
<td>3.3 - 5 days</td>
<td>Duration of infectiousness</td>
</tr>
<tr>
<td>Infection detection rate</td>
<td>15%</td>
<td>1 confirmed case becomes ~7 initial infections</td>
</tr>
<tr>
<td>Percent asymptomatic</td>
<td>50%</td>
<td>Infected individuals that don’t exhibit symptoms</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset to hospitalization</td>
<td>5 days</td>
<td>Time from symptoms to hospitalization</td>
</tr>
<tr>
<td>Hospitalization to ventilation</td>
<td>3 days</td>
<td>Time from hospitalization to ventilation</td>
</tr>
<tr>
<td>Duration hospitalized</td>
<td>8 days</td>
<td>Time spent in the hospital</td>
</tr>
<tr>
<td>Duration ventilated</td>
<td>14 days</td>
<td>Time spent on a ventilator</td>
</tr>
<tr>
<td>Percent hospitalized</td>
<td>5.5% (~20% of confirmed)</td>
<td>Symptomatic individuals becoming hospitalized</td>
</tr>
<tr>
<td>Percent in ICU</td>
<td>20%</td>
<td>Hospitalized patients that require ICU</td>
</tr>
<tr>
<td>Percent ventilated</td>
<td>70%</td>
<td>ICU patients requiring ventilation</td>
</tr>
<tr>
<td>Percent Fatality</td>
<td>1.75%</td>
<td>Symptomatic individuals who die</td>
</tr>
</tbody>
</table>

3 Li et al., Science 16 Mar 2020:eabb3221 [https://science.sciencemag.org/content/early/2020/03/24/science.abb3221](https://science.sciencemag.org/content/early/2020/03/24/science.abb3221) (Accessed 13APRIL2020)
4 Personal communications, UVA Health and Sentara (~500 VA based COVID patients)
Recent Parameter Validation

New York State announced sero-prevalence survey results on May 2\textsuperscript{nd}

- 15,000 antibody tests conducted randomly through the state at grocery stores
- **Total Attack Rate**: 12.3%

**Estimation of undetected infections**

- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12\% of infections (close to 15\% used in model)

**Estimation of hospitalizations from infections**

- Total infections in NY = 2.46M, total of 66K hospitalizations
- Hospitalizations = 2.7\% of infections (close to 2.25\% used in model)
Calibration Approach

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

• **Model:** PatchSim initialized with disease parameter ranges from literature

• **Calibration:** fit model to observed data
  - Search transmissibility and duration of infectiousness
  - Markov Chain Monte Carlo (MCMC) particle filtering finds best fits while capturing uncertainty in parameter estimates

• **Spatial Adjustments:** VDH districts grouped to 3 tiers of growth during the Pause, with similarly scaled reductions then applied to the groups of districts

• **Project:** future cases and outcomes using the trained particles

Accessed 5pm June 16, 2020
https://www.vdh.virginia.gov/coronavirus/
Impact of Interventions
Estimating Effects of Social Distancing

Mobility data shows pause mid-March, slow rebound starting in May

Google Mobility data shows continued slow rebound (as of June 7th)
https://www.google.com/covid19/mobility/

- Regional levels of Stay at home vs. Workplace
- 35% reduction of those staying at home, very slow and stable reductions
- Other activities show vaster increases with grocery / retail nearly back to baseline
- Parks and recreation show significant increase

Weekly growth rate by date of onset
- Week before March 15 = 0.3
- Week after March 15 = -0.03 to 0.04

Crude reproductive number estimates
- 2.2 before March 15th
- 0.81 to 1.10 after March 15th
Estimating Effects of Better Detection

VDH data shows reductions in time from Symptom Onset to Diagnosis

Days to Diagnosis drops ~30% in recent weeks

- Mid March to Late April = 7.9 days
- Late April to Mid May = 5.5 days (30% lower)
- Mid May to end of May = 4.4 days (45% lower)
- Slight shift up from last week (7.5, 5.3, and 4.0)

Testing Encounters increased, though slowing:
~30K/week (late April) to ~8K/day (early June)
Estimating Daily Reproductive Number

**Statewide and most regions follow similar pattern**
- Spike, followed by a decline, to plateau, with recent upswing
- This week: overall decline, some regions up

**Methodology**
- Wallinga-Teunis method as implemented in EpiEstim¹ R package
- Based on Date of Onset of Symptoms
- Uses serial interval to estimate $R_e$ over time: 6 days (2 day std dev)

**Recent Estimates subject to revision as more data comes in**
- Date of onset unstable in last 7-14 days

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Spatial Adjustments at District Level

Case Rate (per 100K) by VDH District

- Regions arranged to rough position in Commonwealth and colored by VDH Health Region
- Considerable variation across districts
- Some consistent behaviors during mid-April to mid-May during the Pause period
- Smoothed (Savitzky-Golay filter)
Spatial Adjustments at District Level

Adjustments based on Growth during Pause

- Group districts by their mean growth from mid-April to mid-May (using model based $R_{eff}$)
- Assign reductions during Pause, and beyond, to members of these groups
- Low reduction = 40%
- Moderate reduction = 45% (previous level)
- High reduction = 55%
Spatial Adjustments at District Level - Daily

Light Rebound – Better Detection projection

- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Regions arranged to rough position in Commonwealth
Spatial Adjustments at District Level - Cumulative

Light Rebound – Better Detection projection

- Cumulative confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Regions arranged to rough position in Commonwealth
Impact of Race / Ethnicity & Outbreaks

Different Races and Ethnicities disproportionately affected
- Hispanic population bears large burden of disease compared to population size

Outbreak Events are hard to predict and affect model fits
- Eastern Shore has 60% of cases from 10 outbreaks
- Fairfax most outbreaks but relatively low proportion
Emerging Hot Spot Analysis

- Runs a Hot Spot Analysis at each time step
- Then a Mann Kendall Test on each county to detect temporal trends
- As with standard analysis, output is based on significance of clusters, not absolute values
Emerging Hot Spot Analysis for COVID19 Incidence
2020-03-01 to 2020-06-13 (weekly)
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
Period of Transition: Sustaining Control

**Weekly New Confirmed Cases**

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>Light Rebound</th>
<th>Steady</th>
<th>Light – Better Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/7/20</td>
<td>13,278</td>
<td>11,900</td>
<td>6,114</td>
</tr>
<tr>
<td>6/14/20</td>
<td>17,222</td>
<td>13,604</td>
<td>5,664</td>
</tr>
<tr>
<td>6/21/20</td>
<td>21,272</td>
<td>15,308</td>
<td>5,178</td>
</tr>
<tr>
<td>6/28/20</td>
<td>25,577</td>
<td>16,889</td>
<td>4,750</td>
</tr>
<tr>
<td>7/5/20</td>
<td>29,608</td>
<td>18,152</td>
<td>4,309</td>
</tr>
<tr>
<td>7/12/20</td>
<td>33,008</td>
<td>19,110</td>
<td>3,874</td>
</tr>
<tr>
<td>7/19/20</td>
<td>34,726</td>
<td>19,565</td>
<td>3,505</td>
</tr>
<tr>
<td>7/26/20</td>
<td>34,472</td>
<td>19,306</td>
<td>3,137</td>
</tr>
<tr>
<td>8/2/20</td>
<td>32,957</td>
<td>18,450</td>
<td>2,850</td>
</tr>
<tr>
<td>8/9/20</td>
<td>30,785</td>
<td>17,274</td>
<td>2,552</td>
</tr>
<tr>
<td>8/16/20</td>
<td>28,774</td>
<td>15,878</td>
<td>2,278</td>
</tr>
<tr>
<td>8/23/20</td>
<td>26,161</td>
<td>14,444</td>
<td>2,005</td>
</tr>
</tbody>
</table>

*Numbers are medians of projections*
District Level Projection - Cumulative

Light Rebound – Better Detection projection

- Cumulative confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Regions arranged to rough position in Commonwealth
Hospital Demand and Capacity by Region

Capacities by Region – Light Rebound with Better Detection
COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds

* Assumes average length of stay of 8 days

Date ranges when regions are estimated to exceed surge capacity

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Date Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Light</td>
<td>Mid June to Late Aug</td>
</tr>
<tr>
<td>2 Steady</td>
<td>Early July to Late July</td>
</tr>
<tr>
<td>3 Light – Better Detection</td>
<td>None</td>
</tr>
<tr>
<td>4 Steady – Better Detection</td>
<td>None</td>
</tr>
<tr>
<td>5 Full Rebound</td>
<td>Mid June to Early August</td>
</tr>
</tbody>
</table>

Social Distancing postponed the time to when capacity could be exceeded, but without other measures we may still reach it in some areas
Medical Resource Demand Dashboard

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

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

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Questions?

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