2023 IDM Annual Symposium

Advancing Simulation Methodology for Identifying Optimal Healthcare Policy During COVID-19 Pandemic

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Background

- Health behaviors are complex and can change over time.
- Modelling studies provides insights into the relationship between health behaviors and policy outcomes for policymakers.

Figure: https://www.sycamoreinstitutetn.org/drivers-of-health/
Questions to tackle COVID-19 pandemic

In order to minimize the disease burden,

1. How effective are non-pharmaceutical interventions (NPIs) when vaccination is unavailable? Can we control the pandemic to the level of Washington state’s objective? Are the results robust to model uncertainty?

2. When viruses keep mutating, will vaccination remain effective policies? Will NPIs remain effective policies?

To address vaccine hesitancy,

3. Given individuals make different vaccination behavior decisions, whom should be targeted to promote vaccination?
Research Question 1

• How effective are non-pharmaceutical interventions (NPIs) when vaccination is unavailable?
• Can we control the pandemic to the level of WA objective?
• Are the results robust to model uncertainty?

Overview of large-scale agent-based model

King County

1.9M Agents

Age
Gender
Race
Health Risk
...

School

Workplace

Household

Neighborhood
Overview of large-scale agent-based model

COVID-19 Natural History Disease Model
- Infectious
  - Pre-symptomatic
  - Severe symptomatic
  - Non-severe symptomatic
  - Recovered or Dead
- Asymptomatic or Paucisymptomatic

Inputs
- Population Demographics
- Contact Networks
- Epidemic Parameters

Public Health Interventions
- Social Distancing
  - Stay-at-home
  - Work-from-home
- Face Mask Use
- School Closure
- Home Quarantine
- Testing
- Contact Tracing

Outcomes
- Reproduction Number $R_0$
- Total Infection
- Total Test
- Total Contact Trace
- Total Home Quarantine
Model calibration

Calibration Parameters

- COVID-19 transmissibility
- Daily contact rate in household, neighborhood, workplace, school
- Basic home quarantine probability

COVID-19 Simulation Model

Targets

- Basic Reproduction Number ($R_0$)
- Reported Deaths

- Calibration period: January 15, 2020, to May 31, 2020
- Fit NPIs compliance history by observing Seattle’s sequence of interventions
- Resulted in seven clusters, narrowed down to two parameter sets (Cluster 2 and Cluster 6)
Calibration results

- Cluster 2: High contacts in **non-school** places (household, neighborhood, workplace)
- Cluster 6: High contacts in **school** setting
Research question 1

1. How effective are non-pharmaceutical interventions (NPIs) when vaccination is unavailable?
2. Can we control the pandemic to the level of Washington state’s objective?
3. Are the results robust to model uncertainty?

<table>
<thead>
<tr>
<th>NPIs</th>
<th>Parameter Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Distancing</td>
<td>Open (0%), Low (20%), Medium (50%), High (80%)</td>
</tr>
<tr>
<td>Face Mask Use</td>
<td>0%, 25%, 50%, 75%, 100%</td>
</tr>
<tr>
<td>School Closure</td>
<td>Open (0%), 25%, Hybrid (50%), 75%, Closed (100%)</td>
</tr>
<tr>
<td>Testing and Contact Tracing</td>
<td>Low, Medium, High</td>
</tr>
</tbody>
</table>
Research question 1-1

How effective are non-pharmaceutical interventions (NPIs) when vaccination is unavailable?
Research question 1-2

Can we control the pandemic to the level of Washington state’s objective?

Cluster 2
- Social Distancing
- Face Mask Use
- School Closure
- Testing + Contact Tracing

Cluster 6
- Social Distancing
- Face Mask Use
- School Closure
- Testing + Contact Tracing

Washington state’s objective
Research question 1-3

Are the results robust to model uncertainty?

Cluster 2
- Social Distancing
- Face Mask Use
- School Closure
- Testing + Contact Tracing

Cluster 6
- Social Distancing
- Face Mask Use
- School Closure
- Testing + Contact Tracing
Findings for research question 1

When the wild strain of SARS-CoV-2 spread and vaccination is unavailable,

- **Face mask use** and **social distancing** are important regardless of model uncertainty.

- **Strong school closure** may be effective only when a society’s student contacts are high.

- Current projections of **testing** and **contact tracing** are insufficient to contain COVID-19 without other NPIs.
Research Question 2

• When viruses keep mutating, will vaccination remain effective policies?
• When viruses keep mutating, will NPIs remain effective policies?
Updated large-scale agent-based model

COVID-19 Natural History Disease Model

- Susceptible
- Exposed
- Infectious
  - Presymptomatic
  - Severe symptomatic
- Non-severe symptomatic
- Asymptomatic or Paucisymptomatic
- Recovered or Dead

Inputs
- Population
- Demographics
- Contact Networks
- Epidemic Parameters

Public Health Interventions
- Social Distancing
  - Stay-at-home
  - Work-from-home
- Face Mask Use
- School Closure
- Home Quarantine
- Testing
- Contact Tracing

Outcomes
- Reproduction Number $R_0$
- Total Infection
- Total Test
- Total Contact Trace
- Total Home Quarantine
Updated large-scale agent-based model

COVID-19 Natural History Disease Model

Susceptible: $S_{x,p}$
Exposed: $E_{x,p}$
Pre-symptomatic: $IPS_{x,p}$
Symptomatic: $IS_{x,p}$
Recovered: $R_{x,p}$
Asymptomatic: $IA_{x,p}$
Infectious: $I_{x,p}$
Death from COVID-19: $D_{x,p}$

Public Health Interventions
- Social Distancing
  - Stay-at-home
  - Work-from-home
- Face Mask Use
- School Closure
- Home Quarantine
- Testing
- Contact Tracing
- Vaccination ($v$)

Inputs
- Population Demographics
- Contact Networks
- Epidemic Parameters
  - Variant ($x$)
  - Immune History ($p$)

Outcomes
- Reproduction Number $R_0$
- Total Infection
- Total Test
- Total Contact Trace
- Total Home Quarantine

$x$: Variant type
$v$: Vaccination history
$p$: Infection history
Model calibration

- Calibration period: January 15, 2020, to December 31, 2020
- Fit NPIs compliance history by observing Seattle’s sequence of interventions
- Resulted in one parameter set
Research question 2

1. When viruses keep **mutating**, will **vaccination** remain effective policies?
2. When viruses keep **mutating**, will **NPIs** remain effective policies?

<table>
<thead>
<tr>
<th>Policy Scenarios</th>
<th>Parameter Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaccination willingness reduction for each additional dose</td>
<td>50% less, <strong>25% less</strong>, Same</td>
</tr>
<tr>
<td>NPI Policy</td>
<td><strong>Timeline 1</strong>, <strong>Timeline 2</strong>, <strong>Threshold</strong></td>
</tr>
</tbody>
</table>
Research question 2

### Virus mutation scenarios

<table>
<thead>
<tr>
<th>Mutation Scenarios</th>
<th>Changes in infectivity</th>
<th>Changes in disease severity</th>
<th>Changes in immune evasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td>Same</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>Same</td>
<td>Neutral</td>
</tr>
<tr>
<td>S3</td>
<td>50% more infectious</td>
<td>Same</td>
<td>Optimistic (Pan-coronavirus vaccine)</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td>50% less severe</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>S5</td>
<td></td>
<td>Same</td>
<td>Neutral</td>
</tr>
<tr>
<td>S6</td>
<td></td>
<td>50% less severe</td>
<td>Optimistic (Pan-coronavirus vaccine)</td>
</tr>
<tr>
<td>S7</td>
<td></td>
<td>Same</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>S8</td>
<td></td>
<td>Same</td>
<td>Neutral</td>
</tr>
<tr>
<td>S9</td>
<td></td>
<td>Same</td>
<td>Optimistic (Pan-coronavirus vaccine)</td>
</tr>
<tr>
<td>S10</td>
<td></td>
<td>Same</td>
<td>Pessimistic</td>
</tr>
<tr>
<td>S11</td>
<td></td>
<td>50% less severe</td>
<td>Neutral</td>
</tr>
<tr>
<td>S12</td>
<td></td>
<td></td>
<td>Optimistic (Pan-coronavirus vaccine)</td>
</tr>
</tbody>
</table>
Research question 2 - 1

When viruses keep mutating, will vaccination remain effective policies?

- 6 mutation scenarios, 3 vaccine willingness
- Increasing vaccination willingness is effective with optimistic immune evasion (pan-coronavirus vaccine, S3 and S12)
Research question 2 - 2

When viruses keep mutating, will NPI policy remain effective policies?

- 6 mutation scenarios, 3 NPI policies
- Strengthening NPI policy **always** reduce mortality, regardless of virus mutation scenarios
Findings for research question 2

When the SARS-CoV-2 keep mutates,

• Developing *pan-coronavirus vaccine* has high potential in reducing death toll with increased vaccination willingness

• Strengthening *NPI policy* is robust to viral mutation
Research Question 3

- To address vaccine hesitancy, given individuals make different vaccination behavior decisions, whom should be targeted to promote vaccination?
Networked compartmental model

Disease contagion

Opinion Propagation
Networked compartmental model

Regional Group

Age Group
Research question 3

Given individuals make different vaccination behavior decisions, whom should be targeted to promote vaccination?

Ongoing research approach

– Vaccination behavior decision depends on rational and emotional judgement and active pro-vaccination neighbors who share opinions
– Allocate resources by age and geographic groups
– Get near-optimal solutions while considering fairness
Thank you! Questions?
Appendix
Model calibration

• Step 1
  – Use Latin hypercube sampling method to generate 1,000 parameter sets.
  – Randomly infect 10 random people and simulate for 30 days.
  – Select parameter sets whose basic reproduction number ($R_0$) is within range (1.5-3.5)

• Step 2
  – Cluster the selected parameter sets and get centroid of each cluster
  – With the centroid points, simulate for the full calibration period.
  – Select centroid points whose simulated infection-fatality ratio is within range (0.005-0.008)
Model calibration

• Step 1
  – Use Latin hypercube sampling method to generate 1,000 parameter sets.
  – Randomly infect 10 random people and simulate for 30 days.
  – Select parameter sets whose basic reproduction number ($R_0$) is within range (2-4)

• Step 2
  – Cluster the selected parameter sets and get centroid of each cluster
  – With the centroid points, simulate for the full calibration period.
  – Select centroid points with the lowest mean absolute error on health outcomes
Bivalent vaccination rate

King County, WA (May 10, 2023)

Select a vaccination status: Received updated booster

What percent of residents received an updated booster?

<table>
<thead>
<tr>
<th>By age group</th>
<th>Overall</th>
<th>0-4 years old</th>
<th>5-11 years old</th>
<th>12-17 years old</th>
<th>18-34 years old</th>
<th>35-49 years old</th>
<th>50-61 years old</th>
<th>65+ years old</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
<td>2%</td>
<td>29%</td>
<td>29%</td>
<td>34%</td>
<td>43%</td>
<td>23%</td>
<td>70%</td>
</tr>
</tbody>
</table>

Date of dose:
- 2/1/2021
- 6/1/2021
- 8/1/2022
- 8/1/2023