The IHME COVID-19 Model

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Origin of the model

• Primary goal to provide estimates of COVID-19 patient hospital utilization to help hospital systems plan for the upcoming surge
  o Initially a response to a request from UW Medicine but demand prompted expansion to all US States and countries

• Key features
  o Projections for next 3 months
  o Regular updates
  o Started modeling deaths & resource use
  o Expanded to infections and testing
Model forecasts and scenarios

- Epidemiological outputs: infections, deaths, antibody prevalence
- Health system outputs: hospitalizations, ICU admissions, and ventilator need
- As part of the modeling process, produce forecasts of testing per capita, mobility per capita, social distancing mandates, mask use and seasonality
- We produce a reference forecast, what we think is most likely to happen but the model allows exploration of many scenarios
Covid Model Development over the past 2 months

<table>
<thead>
<tr>
<th>CurveFit</th>
<th>Curvefit-SEIR Hybrid</th>
<th>RCKS-SEIR Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 26 – May 3</td>
<td>May 4 – present</td>
<td></td>
</tr>
<tr>
<td>• Statistical, deaths-based model</td>
<td>• Mixture of CurveFit and SEIR</td>
<td>• No more CurveFit</td>
</tr>
<tr>
<td>• Performed well for locations with &gt;50 deaths</td>
<td>• Fitted a statistical model to the past and next 8 days; and an SEIR model to predict after 8 days</td>
<td>• Analysis of cases corrected for testing trends, hospitalizations, and deaths to estimate past &amp; next 8 days</td>
</tr>
<tr>
<td>• Focused on predicting initial peak of hospital resource use as a function of social distancing</td>
<td>• Better fit to observed declines after peak</td>
<td>• Fit an SEIR model to these trends</td>
</tr>
<tr>
<td>• Limited in application to countries with &gt;50 deaths</td>
<td>• Still some limitations around variable input data and small epidemics</td>
<td>• Additional covariates: mask use, human contact rates, pneumonia seasonality</td>
</tr>
<tr>
<td></td>
<td>• Additional covariates: mobility, testing, temperature, pop density</td>
<td></td>
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</tbody>
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Key steps in the RKCS-SEIR model

1) Combine data on cases correcting for trends in testing, hospitalizations, and deaths into a coherent trend in daily deaths with uncertainty.

2) Resample 1000 draws of daily deaths from this trend for each location.

3) Using estimated infection fatality rate by age and the distribution of time from infection to death, use daily deaths to generate 1000 distributions of estimated infections by day in the past.

4) Fit SEIR model with beta varying over time to the trend in estimated infections 1000 times to generate 1000 SEIR models. Other SEIR parameters like gamma, sigma, alpha sampled over defined ranges.

5) Estimate the statistical relationship between beta(t) and covariates.
Key steps in the RKCS-SEIR model

6) Forecast covariates
7) Predict beta(t) as a function of forecasted covariates
8) Use predicted beta(t) to estimate infections, deaths in the future
9) Take predicted infections and deaths and a hospital use microsimulation to estimate hospital resource need.
Random knot combination spline
<table>
<thead>
<tr>
<th>Super Region</th>
<th>Total deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>345,998 (343,827, 349,916)</td>
</tr>
<tr>
<td>Southeast Asia, East Asia, and Oceania</td>
<td>2,900 (2,842, 2,974)</td>
</tr>
<tr>
<td>Central Europe, Eastern Europe, and Central Asia</td>
<td>11,221 (11,058, 11,410)</td>
</tr>
<tr>
<td>High-income</td>
<td>245,010 (244,590, 245,373)</td>
</tr>
<tr>
<td>Latin America and Caribbean</td>
<td>59,742 (57,628, 63,651)</td>
</tr>
<tr>
<td>North Africa and Middle East</td>
<td>16,590 (16,490, 16,856)</td>
</tr>
<tr>
<td>South Asia</td>
<td>8,201 (8,006, 8,486)</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>2,332 (2,213, 2,600)</td>
</tr>
</tbody>
</table>
Excess Mortality (all causes) vs COVID confirmed deaths

Spain: Cumulative Deaths Since 04 March

Ecuador: Cumulative Deaths Since 14 March

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Ultra-fast computational solution for SEIR models

• Our Mathematical Sciences and Computational Algorithms group developed a way to fit 250,000 SEIR models in less than an hour allowing us to estimate 1000 SEIR models for each location reflecting uncertainty in cases, hospitalizations and deaths.

• Allows IHME model to incorporate a wide range of sources of uncertainty into the creation of the model pool.
Predicting beta(t)

- Wide range of covariates tested or being tested: population density, household size, public transport, urban slums, flu seasonality, pneumonia seasonality, mobility, mask use, self-reported number of contacts, testing per capita, mandates, sum of mandates.

- To date, regression analysis shows strong relationships for pneumonia seasonality, mobility, mask use, testing per capita, population density.

- These variables used in current iteration of model.
Mask Use: Facebook survey

Percent who always wear a mask

- [0 – 10]
- [10 – 20]
- [20 – 30]
- [30 – 40]
- [40 – 50]
- [50 – 60]
- [60 – 70]
- [70 – 80]
- [80 – 90]
- [90 – 100]
Pneumonia deaths by week

MR-BRT Analysis Results: United States of America

Ratio of Pneumonia Deaths: United States of America
Covid daily testing per 100,000
Cellphone app Mobility Data in Madhya Pradesh, India and Western Cape, South Africa

Madhya Pradesh

Western Cape
Mobility forecasted on June 1
Mandates by region and time
Brazil
Mexico

R effective on May 15

Mexico

![Graph showing R effective on May 15 in Mexico]

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R effective on May 15

Italy
Highest numbers of cumulative COVID-19 deaths projected in:

- UK
- Italy
- Spain
- France
- Belgium
- Sweden
Projected total Covid-19 infections and deaths by August 4, 2020

<table>
<thead>
<tr>
<th>Region</th>
<th>Estimated Infections (lower, upper)</th>
<th>Deaths (lower, upper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>307,472,896 (147942289, 646396051)</td>
<td>733,875 (588021, 969483)</td>
</tr>
<tr>
<td>Southeast Asia, East Asia, and Oceania</td>
<td>9718136 (3017274, 37562436)</td>
<td>7813 (5534, 12554)</td>
</tr>
<tr>
<td>Central Europe, Eastern Europe, and Central Asia</td>
<td>4000801 (2659770, 7352651)</td>
<td>24391 (19114, 34338)</td>
</tr>
<tr>
<td>High-income</td>
<td>46496903 (34633480, 69935667)</td>
<td>321032 (295840, 365580)</td>
</tr>
<tr>
<td>Latin America and Caribbean</td>
<td>132796828 (72436584, 224483983)</td>
<td>279295 (196309, 412448)</td>
</tr>
<tr>
<td>North Africa and Middle East</td>
<td>15545922 (6202599, 34608869)</td>
<td>31788 (20647, 72123)</td>
</tr>
<tr>
<td>South Asia</td>
<td>50404703 (12816648, 162194657)</td>
<td>46416 (26255, 80996)</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>48509598 (6539539, 189972973)</td>
<td>23137 (8249, 60836)</td>
</tr>
</tbody>
</table>
How our model can be used for planning

• Planning:
  o Plan what hospital resources are likely needed for the weeks and months ahead
  o Important to plan for upper range of estimates

• Tool getting better all the time:
  o New data
  o Improved models
  o Constantly refining with feedback

https://covid19.healthdata.org/projections
IHME COVID-19 Model: U.S. National Policy Impact

• White House used the model to inform the nationwide mandates on social distancing, and has since engaged with IHME daily on the projections.
IHME COVID-19 Model: Policy Impact in the EU

- IHME’s Model used to allocate PPE and medical equipment resources, such as ventilators and testing kits, via its ‘Clearing house for medical equipment’ – in order to match demand by the Member States.
Forthcoming

- New RKCS-SEIR model to be released this week for some locations
- Estimates now produced for all countries – will release estimates once we have had some discussion with local collaborators for face validity checks.
- In some countries, continue to have concerns that low testing rates and low case and death counts may be masking true extend of the epidemic.
- Time window will be extended through October 1 by mid-June; then possibly through December 31, 2020.
- Formal evaluation of forecast accuracy of IHME three generations of models and other models that produce publicly available estimates for multiple countries.
Comparing COVID-19 model performance
Median absolute percent error at 4 weeks

Weekly error

Cumulative error
Thank You

https://www.healthdata.org