Assessments of Mitigations Strategies for SARS-CoV-2 Using a Mathematical Epidemiological Model

Frances M. Aponte Caraballo
Biology Department
University of Puerto Rico
Cayey Campus

Nebraska Conference for Undergraduate Women in Mathematics 2021
Outline

- COVID-19 timeline
- Monthly Analysis
- Association between events and Daily Cases
- Epidemiological Model
- $R$ and $R_0$

Getting perspective

- COVID-19 disease is caused by the SARS-CoV-2 virus.
- Respiratory disease
Dashboard COVID-19 (case reporting tool)

Puerto Rico COVID-19

Total Casos: 80,590
Total Casos Probables: 5,933
Total Casos: 61,432
Total Muertes COVID-19: 1,703

Casos Confirmados por Municipio

Casos Confirmados por Región de Salud

Casos Confirmados por Región de Salud

https://experience.arcgis.com/experience/852c30ea3baa48278175c13c211728e0/
Testing

---

PCR test (Molecular test): Confirmed Cases
Antigens test: Probable Cases
Antibody test (Seroologic test): Suspected Cases
Estimated epidemic curve based on daily case reporting until October

**Covid-19 Confirmed (PCR Test) Active Cases in Puerto Rico**

- Full Lockdown Approximation: April 1, 2020
- First Report of Positive Cases: March 10, 2020
- First Recovered Case: April 24, 2020
- Restaurant openings at 25% capacity: May 21, 2020
- “Noche de San Juan”: June 24, 2020
- Full Lockdown is over: June 24, 2020
- Independence Day: July 4, 2020
- Maximum Capacity: July 1, 2020
- “Capacity at 75%”: June 29, 2020
- Capacity Reduction at 50%: July 16, 2020
- USA Independence Day: July 4, 2020
- “Capacity at 50%”: July 22, 2020
- “Cross Contamination on 1478 Quest test”: October 1, 2020
- “Lockdown alarm eliminated”: October 27, 2020
- “Lockdown on Sundays are over”: September 11, 2020
- Capacity reduction at 25% and political caravans prohibited: August 22, 2020
- 2nd round Political Primaries: August 16, 2020
- 1st round Political Primaries: August 9, 2020
- Cross Contamination on 1478 Quest test: October 31, 2020
- Public Transport activated: October 26, 2020
- Capacity at 55%, Gym, cinemas, cinema at 30%: October 16, 2020
- Halloween, Political Campaigning closures: November 1, 2020
- Manifestation to open schools: October 3, 2020
- Lockdown on Sundays are over: September 11, 2020

© Frances Aponte, 2020
Closure of Political Campaigns

Election Day

3 CESCO units closes

Massive antigen testing. 911 emergency office closes.

10 doctors hospitalized

Massive antigen testing. AILMM & AMA protocol violation.

Massive antigen testing. Vaccines expected for December

Lockdown 10pm-5am

Massive educational campaigns

Massive antigen testing. Pfizer vaccine 95% efficacy.

First study of seroprevalence in the island.

Seroprevalence study was launch

Gyms, casinos, cinema churches at 30%. National Guard activated.

Some establishment closed due to executive order violation

AILMM & AMA protocol violation

Over 100 patients in the ICU

Political related protest. PR at level 4 for travelers

Thanksgiving

Black Friday

Tourist intervention at the AILMM, protocol violation

Baby from an infected mother born with antibody's for COVID-19 (Singapore)

All month: Conglomerate activities due to vote scrutiny

© Frances Aponte, 2020
December 2020

Full Lockdown on Sundays
Lockdown 9 pm – 5 am
30% Capacity
Gyms, cinema, casino closed

Some establishment
closed due to
executive order
violation

Massive
antigen
testing

Pfizer
Vaccine
Approved by FDA

Modern Vaccine
Approved by
FDA

New covid variant
reported in United
Kingdom

Vaccination
started

New Years Eve

Genomic surveillance
system stablished

New covid variant
detected in USA

© Frances Aponte, 2020
## Executive Orders

<table>
<thead>
<tr>
<th>Full Lockdown 24/7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OE-2020-029</strong></td>
</tr>
<tr>
<td><strong>OE-2020-033</strong></td>
</tr>
<tr>
<td><strong>OE-2020-038</strong></td>
</tr>
<tr>
<td><strong>OE-2020-041</strong></td>
</tr>
<tr>
<td><strong>OE-2020-044</strong></td>
</tr>
</tbody>
</table>
COVID-19 Positive Cases: Puerto Rico

<table>
<thead>
<tr>
<th>Date</th>
<th>Confirmed</th>
<th>Probable</th>
<th>Suspected</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Apr</td>
<td>964</td>
<td>0</td>
<td>611</td>
<td>1575</td>
</tr>
<tr>
<td>31-May</td>
<td>340</td>
<td>0</td>
<td>1958</td>
<td>2298</td>
</tr>
<tr>
<td>30-Jun</td>
<td>425</td>
<td>0</td>
<td>3239</td>
<td>3664</td>
</tr>
<tr>
<td>31-Jul</td>
<td>4814</td>
<td>0</td>
<td>5521</td>
<td>10335</td>
</tr>
<tr>
<td>31-Aug</td>
<td>9041</td>
<td>0</td>
<td>6508</td>
<td>15549</td>
</tr>
<tr>
<td>30-Sep</td>
<td>8592</td>
<td>0</td>
<td>7054</td>
<td>15646</td>
</tr>
<tr>
<td>31-Oct</td>
<td>10365</td>
<td>0</td>
<td>7229</td>
<td>17594</td>
</tr>
<tr>
<td>30-Nov</td>
<td>17106</td>
<td>0</td>
<td>9159</td>
<td>27938</td>
</tr>
<tr>
<td>31-Dec</td>
<td>20680</td>
<td>1673</td>
<td>14937</td>
<td>38671</td>
</tr>
</tbody>
</table>

Incidence
COVID-19 Deaths: Puerto Rico

<table>
<thead>
<tr>
<th></th>
<th>30-Apr</th>
<th>31-May</th>
<th>30-Jun</th>
<th>31-Jul</th>
<th>31-Aug</th>
<th>30-Sep</th>
<th>31-Oct</th>
<th>30-Nov</th>
<th>31-Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confirmed</td>
<td>40</td>
<td>33</td>
<td>-14</td>
<td>56</td>
<td>173</td>
<td>204</td>
<td>140</td>
<td>265</td>
<td>360</td>
</tr>
<tr>
<td>Probable</td>
<td>54</td>
<td>9</td>
<td>31</td>
<td>16</td>
<td>37</td>
<td>26</td>
<td>27</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>Suspected</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
<td>42</td>
<td>17</td>
<td>72</td>
<td>210</td>
<td>230</td>
<td>167</td>
<td>290</td>
<td>399</td>
</tr>
</tbody>
</table>
### Description (Jan 23, 2021)

<table>
<thead>
<tr>
<th>Description</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confirmed Cases</td>
<td>83,670</td>
</tr>
<tr>
<td>Probable Cases</td>
<td>6,403</td>
</tr>
<tr>
<td>Suspected Cases</td>
<td>64,390</td>
</tr>
<tr>
<td>Convalescence Cases</td>
<td>73,760</td>
</tr>
<tr>
<td>Fatalities</td>
<td>1,771</td>
</tr>
</tbody>
</table>
COVID-19 epidemic curve estimate based on test date
Interventions

• Mitigate or Suppress
  • Reduce severity
  • Drastic decisions

• Non-pharmaceutical interventions
  • Social-distancing (physical distance more than 6ft)
  • Mask usage

• Treatments & Vaccines
  • Pfizer 95% efficacy
  • December 2020
What's next?

Table 2: Parameters of the model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Incubation Period</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Infection rate</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Rate of developing symptoms</td>
</tr>
<tr>
<td>$\xi$</td>
<td>Protected rate</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Convalescent Period</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Hospitalization Period</td>
</tr>
<tr>
<td>$C$</td>
<td>Number of convalescent cases</td>
</tr>
<tr>
<td>$D$</td>
<td>Number of deceased from population</td>
</tr>
<tr>
<td>$E$</td>
<td>Number of exposed from population</td>
</tr>
<tr>
<td>$H$</td>
<td>Number of hospitalized from population</td>
</tr>
<tr>
<td>$I$</td>
<td>Number of infected from population</td>
</tr>
<tr>
<td>$N$</td>
<td>Total population of the sample</td>
</tr>
<tr>
<td>$S$</td>
<td>Number of susceptible cases</td>
</tr>
</tbody>
</table>

Figure 2: SEIACH population Model

$$\lambda = \frac{\varepsilon_1 \beta_1 S A}{N} + \frac{\varepsilon_2 \beta_2 S I}{N}$$
\[ \dot{S} = -\left( \frac{\varepsilon_1 \beta_1 SA}{N} + \frac{\varepsilon_2 \beta_2 SI}{N} \right) \]  
(1)

\[ \dot{E} = \frac{\varepsilon_1 \beta_1 SA}{N} + \frac{\varepsilon_2 \beta_2 SI}{N} - \kappa \alpha E - (1 - \kappa) \alpha E \]  
(2)

\[ \dot{I} = \kappa \alpha E - \sigma I - \varphi_2 I \]  
(3)

\[ \dot{A} = (1 - \kappa) \alpha E - \varphi_1 A \]  
(4)

\[ \dot{H} = \sigma I - \mu H - \varphi_3 H \]  
(5)

\[ \dot{C} = \varphi_1 A + \varphi_2 I + \varphi_3 H \]  
(6)
Results
Model Solution using Scilab
Basic reproductive number

- Number of secondary infections that are produced in a total susceptible population by an infected individual during the infectious period.

\[ R_0 = \frac{\varepsilon_1 \beta_1 \kappa \varphi_1 + \varepsilon_2 \beta_2 (-\kappa + 1)(\sigma + \varphi_2)}{\varphi_1 (\sigma + \varphi_2)} \]
$R_0$ using USA estimated parameters

<table>
<thead>
<tr>
<th>Age Group</th>
<th>$R_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-49</td>
<td>1.1</td>
</tr>
<tr>
<td>50-64</td>
<td>1.785</td>
</tr>
<tr>
<td>65 or more</td>
<td>1.62</td>
</tr>
</tbody>
</table>
Effective reproductive number

- The Number of secondary cases that are produced by an infected individual in a population made up of both susceptible and non-susceptible hosts during the infectious period.

\[ R = R_0 \frac{S_t}{N} \]
Effective Number (R)
What is the final Goal?

SEIACH model development.

Parameters identification.

Monthly Data Analysis.

Coding and Data collection from PR.

Overlapping data and chronological events.

Approximation of the parameters from the data.

Application of the SEIACH model with PR parameters.
Closing Remarks

• Executive orders with more restrictive measures are essential to managing the epidemic here in Puerto Rico.

• Non-pharmaceutical interventions, social-distancing, and mask usage interventions must be reinforced until furthers treatments or vaccines are available for the entire population.

• Incorporate the parameter estimation from the data.

• Forecast epidemic outcomes in Puerto Rico applying interventions.
Acknowledgement

• Thanks to the Interdisciplinary Research Institute and the Puerto Rico Louis Stokes Alliance for Minority Participation (PRLSAMP) for the funding (NSF-HRD 2008186) and support of this research work.

• Research mentor: Maytéé Cruz-Aponte, Ph.D.
Assessments of Mitigations Strategies for SARS-CoV-2 Using a Mathematical Epidemiological Model

Frances M. Aponte Caraballo
Biology Department
University of Puerto Rico
Cayey Campus

Nebraska Conference for Undergraduate Women in Mathematics 2021