Covid-19 Model and Matlab Implementation

Glenn Ledder

Department of Mathematics
University of Nebraska-Lincoln
gledder@unl.edu

February 12, 2021
UNL Mathematical Epidemiology Teaching Modules

- Two Formats
  - Spreadsheet-Based ('S')
  - Program-Based ('P')

- Three Models
  1. SIR (S1 and P1)
  2. SEIR (S2 and P2)
  3. COVID-19 model (S3 and P3)

https://www.math.unl.edu/sir-modeling (SIR and SEIR)
https://www.math.unl.edu/covid-module
‘P’ (program-based) Module Contents

1. Introduction (ppt for students)
2. Student Notes (general description: module and model)
3. Programs (function program and three drivers)
4. Instructions (how to use the drivers, some modifications)
5. Questions (centered on experiments)
6. Answers (available only to instructors)
Covid-19 Model and Matlab Implementation

SEIR epidemic model

- **Susceptible Class**
- **Exposed (latent) Class**
  - Already infected
  - Cannot transmit the disease
- **Infectious Class**
  - Can transmit the disease
- **Removed Classes**
  - Can no longer transmit the disease
  - Cannot be reinfected

**Classes are epidemiological, not clinical.**
Classes E, I, and R may or may not have symptoms. Deceased individuals are in class R.
SEIR epidemic model

Let $N = S + E + I + R$.

- $N' = 0$, so $N$ is constant. We can use the variables for population fractions with $N = 1$. 

\[ S' = -\beta SI \]
\[ E' = \beta SI - \eta E \]
\[ I' = \eta E - \gamma I \]
\[ R' = \gamma I \]
The SEAIHRD Model (expanded SEIR)

- Susceptible Classes
  - Susceptible
- Exposed (latent) Classes
  - Exposed
- Infectious Classes
  - Asymptomatic
  - Infectious$_1$ (mild symptomatic—will not be hospitalized)
  - Infectious$_2$ (severe symptomatic—will be hospitalized)
  - Hospitalized
- Removed Classes
  - Recovered (or vaccinated)
  - Deceased
The SEAIHHRD Model

\[ S \xrightarrow{\beta SX} E \xrightarrow{(1-p_a-p_h)\eta E} I_1 \xrightarrow{\alpha A} A \]
\[ \xrightarrow{p_a\eta E} A \xrightarrow{\gamma I_1} R \]
\[ \xrightarrow{p_h\eta E} I_1 \xrightarrow{(1-m)\nu H} I_2 \xrightarrow{\sigma I_2} H \]
\[ \xrightarrow{m\nu H} D \]

- X is the ‘effective number of infectives.’
  - Unconfirmed symptomatic infectives count as 1; other categories count as less than 1.
\[ X = f_c(p_c I + p_{ca} A) + \delta[(1 - p_c) I + f_a(1 - p_{ca}) A] + f_h H. \] (1)

- \(p_c\) and \(p_{ca}\) are the fractions of confirmed cases for symptomatic and asymptomatic infectives.
- \(f_c, f_a, f_h\) are the infectivities of confirmed cases, asymptomatics, and hospitalized cases, relative to an unconfirmed symptomatic infective.
- \(\delta\) is a ‘contact factor’ that incorporates physical distancing and mask use for unconfirmed cases.
The Programs

- **covid19_sim**
  - function program that runs the simulation

- **COVID19_simtest**
  - driver script that presents results for one simulation

- **COVID19_simplot**
  - driver script that runs multiple simulations with one variable parameter

- **COVID19_paramstudy**
  - driver script that plots outcomes as a function of one parameter
Function Program – covid19_sim

- Inputs (other parameters hard coded):
  - contact factor ‘delta’
  - confirmation fraction (symptomatics) ‘pc’
  - confirmation fraction (asymptomatics) ‘pca’
  - doubling time ‘t2’
  - initial class H per 100K ‘H0’
  - initial immune fraction ‘V’

- Outputs:
  - \([S,E,A,I,H,R,D]\)
  - \(R_0\)

- Used by scripts: COVID19_simtest, COVID19_simplot, COVID19_paramstudy
1. Fire up Octave online
2. Show covid19_sim.m code
COVID19_simtest (runs one simulation)

```matlab
%% SCENARIO DATA
delta = 1;
pc = 0.1;
pca = 0;
t2 = 3.1; % gives R0=5.7
H0 = 1; % (per 100K)
V = 0;

etc
```

- Returns matrix of daily class counts
- Plots epidemic progress, particularly new cases, hospitalizations, and deaths
COVID19_simtest examples

1. Run COVID19_simtest with default scenario
2. Modify scenario for one intervention
3. Restore parameter values
COVID19_simtest example: default scenario

The graphs illustrate the simulation results for a default scenario in the COVID-19 model implemented in Matlab. The graphs show the population fractions over days, the number of new cases per 100K population, US deaths (thousands), and hospitalizations per 100K population. The model tracks the dynamics of susceptible (S), exposed (E), asymptomatic ill (A), ill (I), hospitalized (H), recovered (R), and deceased (D) individuals over time.
COVID19_simplot (compares scenarios)

%% DEFAULT SCENARIO DATA

delta = 0.3;
pC = 0.1;

%% INDEPENDENT VARIABLE DATA

xvals = [1, 0.8, 0.6, 0.4];

%% COMPUTATION

for n=1:N
    delta = xvals(n);
    [S,E,A,I,H,R,D,R0] = covid19_sim(delta, pc, etc)
end
COVID19_simplot examples

1. Show default scenario.
2. Change delta values.
3. Show effect of testing with delta=0.3.
COVID19_simplot example (blunting the surge)
COVID19_paramstudy (one parameter as ind. var.)

- Show default scenario.
COVID19_paramstudy (one parameter as ind. var.)

- max hospitalized (per 100K)
- deaths (1000s out of 325M)
- percent S at end
- max new cases
- end condition

Graphs showing the impact of delta on various outcomes.
Experiments and Questions

- 2 warmup questions

- 7 experiments with questions
  1. Flattening the Curve (1 question)
  2. Blunting the Surge (2 questions)
  3. Limited Lockdown (1 question)
  4. Testing Rate (1 question)
  5. Doubling Time (1 question)
  6. Herd Immunity (4 questions)
  7. Contact tracing (3 questions)

- 2 followup questions
Some Fact-Checking Questions

▶ Many questions focus on public statements.

- **A 15-day lockdown will have a permanent benefit**
  (*Surgeon General Jerome Adams, March 18*)

- Expected deaths 100K to 200K with reasonable public health measures (*Dr. Anthony Fauci, April 1*)

- **All testing does is increase the case count**
  (*President Donald Trump, numerous times*)

- The current low case count in New York is due to herd immunity, not public health measures
  (*Senator Rand Paul, September 22*)
Limited Lockdown (Experiment 3, Question 6)

▶ In an interview on The Today Show on March 18, US Surgeon General Jerome Adams (an anaesthesiologist, not an infectious disease expert) said, “If we can get all America to pitch in for the next 15 days, we can flatten the curve.” This suggests that a 15-day total lockdown would have had a permanent benefit.

▶ Other government experts suggested 45 days would be needed.

▶ Can we assess these claims?
  ○ Modify COVID19_simplot to take $\delta = 0$ for $N$ days and then $\delta = 1$.

What do you think will happen?
Limited Lockdown results

- No change in severity!
- 17-day delay for 15-day lockdown.
- 52-day delay for 45-day lockdown.
7. Use COVID19_simplot and COVID19_paramstudy with \( \delta = 0.3 \) (a reasonable estimate for current social practice) to study the impact of testing on the actual progress of the epidemic. Probably it is possible to achieve a confirmation fraction as high as 80% with very thorough testing (but note this is the percentage of symptomatics who are tested—we are still assuming that the 40% who are asymptomatic are not being tested at all). Run simplot with \( p_c \) values of 0.1, 0.5, and 0.8, and run paramstudy with the range \( 0 \leq p_c \leq 1 \). Describe and explain the results.
Testing Rate results
Resources and New Developments

▶ See https://www.math.unl.edu/covid-module for the COVID-19 teaching module and Matlab program suite.

▶ **Shoot me an email to receive updates or offer feedback!**
  gledder@unl.edu

▶ Current research focuses on adding vaccination:
  ○ Delivery is slow, efficacy is less than 100%, acceptance is less than 100%
  ○ Higher risk individuals are vaccinated sooner than lower risk individuals.
  ○ Does vaccination decrease infectivity or severity? (We assume infectivity for now.)
The PSEAIHRD Model

- $v$ is the vaccination rate
- $p$ and $q$ depend on vaccination progress $P/P(0)$
PSEAIHRD Vaccination Details

\[ \frac{dW}{dt} = - \frac{v_m W}{W_h + W}, \quad v = \frac{v_m P}{W_h + W}. \]  

- \( W \) is the fraction of people who want vaccination.
- \( v_m \) is the supply-limited maximum vaccination rate (population fraction per day).
- \( W_h \) is the fraction of potential ‘vaccinees’ for which the vaccination rate is half of the maximum.
- \( d \) is the fraction of initial susceptibles who ‘dissent’ from vaccination. \( W(0) = 1 - d, \quad P(0) = (1 - d)S_0 \)
Vaccination Rate

\[ V = \frac{v_m W}{W_h + W}. \]