Covid-19 Model and Matlab Implementation

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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)

SEIR epidemic model

- **S**usceptible Class
- **E**xposed (latent) Class
  - Already infected
  - Cannot transmit the disease
- **I**nfectious Class
  - Can transmit the disease
- **R**emoved 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

$$\boxed{S} \xrightarrow{\beta SI} \boxed{E} \xrightarrow{\eta E} \boxed{I} \xrightarrow{\gamma I} \boxed{R}$$

$$S' = -\beta SI$$

$$E' = \beta SI - \eta E$$

$$I' = \eta E - \gamma I$$

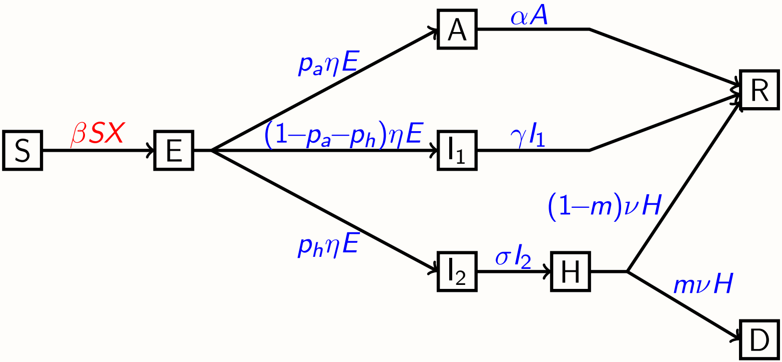
$$R' = \gamma I$$

- Let $N = S + E + I + R$.
  - $N' = 0$, so N is constant. We can use the variables for population fractions with $N = 1$.

The SEAIIHRD Model (expanded SEIR)

- Susceptible Classes
  - **S**usceptible
- Exposed (latent) Classes
  - **E**xposed
- Infectious Classes
  - **A**symptomatic
  - **I**nfectious$_1$ (mild symptomatic—will not be hospitalized)
  - **I**nfectious$_2$ (severe symptomatic—will be hospitalized)
  - **H**ospitalized
- Removed Classes
  - **R**ecovered (or vaccinated)
  - **D**eceased

The SEAIIHRD Model



- X is the 'effective number of infectives.'
  - Unconfirmed symptomatic infectives count as 1; other categories count as less than 1.

SEAIHRD Infectivity Details

$$\boxed{S} \xrightarrow{\beta S X} \boxed{E}$$

$$X = f_c(p_c I + p_{ca} A) + \delta[(1 - p_c)I + f_a(1 - p_{ca})A] + f_h H. \qquad (1)$$

- 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.
- δ 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]
  - $\mathcal{R}_0$
- Used by scripts: **COVID19_simtest**, **COVID19_simplot**, **COVID19_paramstudy**

covid19_sim.m

1. Fire up Octave online
2. Show covid19_sim.m code

COVID19_simtest (runs one simulation)

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

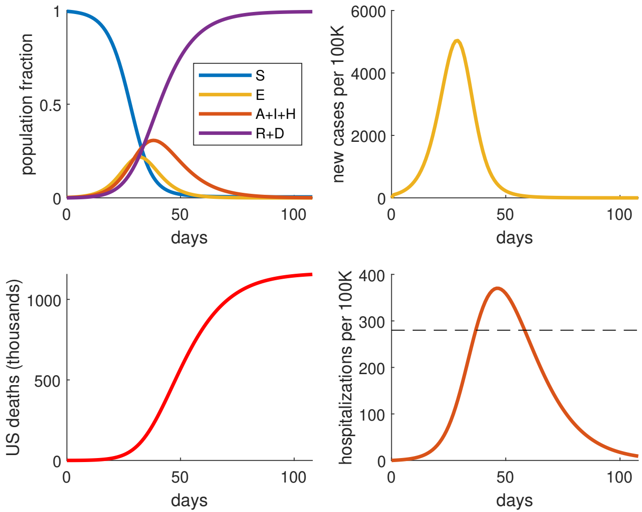
etc

- 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



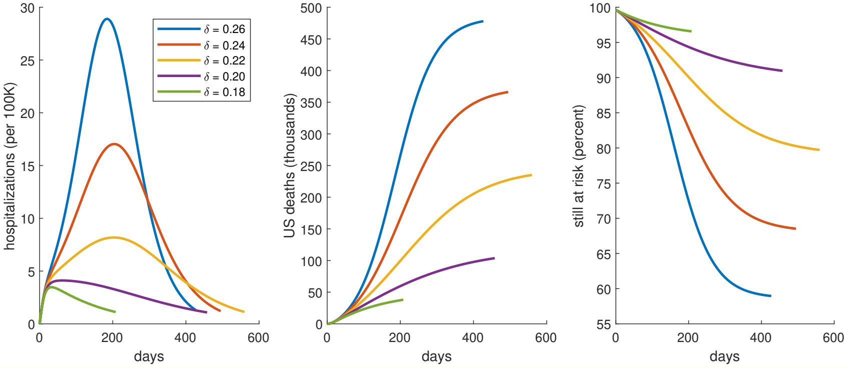
COVID19_simplot (compares scenarios)

```
%% DEFAULT SCENARIO DATA
delta = 0.3;
pc = 0.1;
etc

%% 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)
   etc
end
```

COVID19_simplot examples

1. Show default scenario.
2. Change delta values.
3. Show effect of testing with delta=0.3.

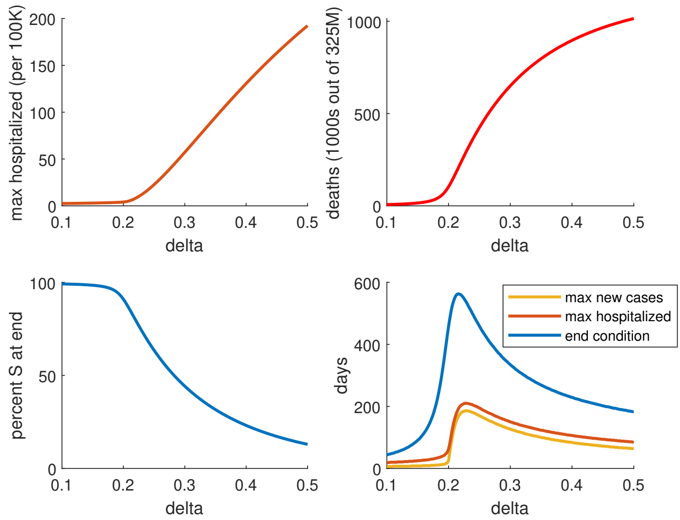
COVID19_simplot example (blunting the surge)



COVID19_paramstudy (one parameter as ind. var.)

- Show default scenario.

COVID19_paramstudy (one parameter as ind. var.)



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

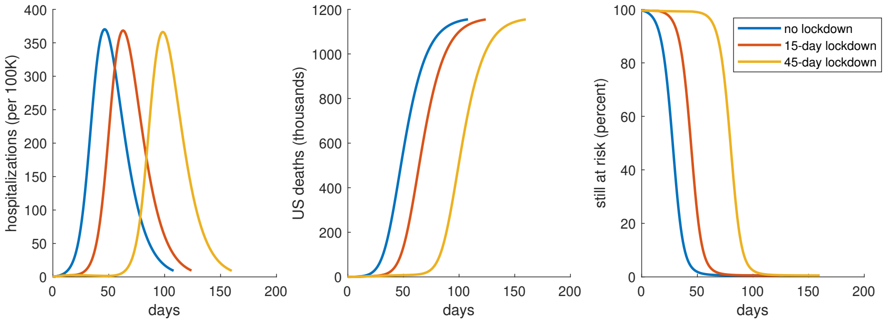
- Many questions focus on public statements.
  - **A 15-day lockdown will have a permanent benefit** (*Surgeon General Jerome Adams, March 18*)
  - Expected deaths 100K to 200K with reasonable public health measures (*Dr. Anthony Fauci, April 1*)
  - **All testing does is increase the case count** (*President 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

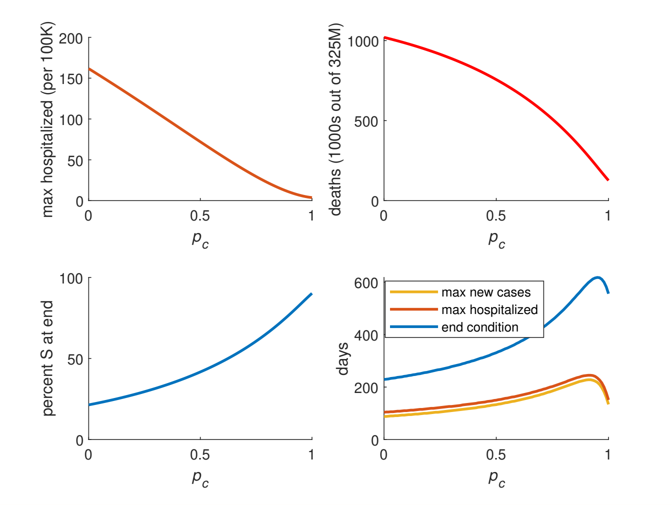


- **No change in severity!**
- 17-day delay for 15-day lockdown.
- 52-day delay for 45-day lockdown.

Testing Rate (Experiment 4, Question 7)

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.

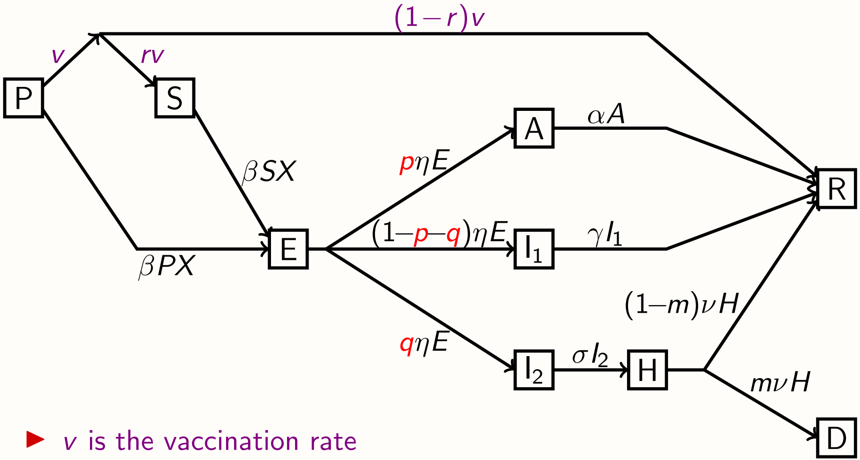
Testing Rate results



Resources and New Developments

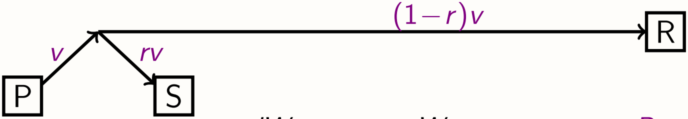
- See **https://www.math.unl.edu/covid-module** for the COVID-19 teaching module and Matlab program suite.
- **Shoot me an email to receive updates or offer feedback!** gledder@unl.edu
- Current research focuses on adding vaccination:
  - Delivery is slow, efficacy is less than 100%, acceptance is less than 100%
  - Higher risk individuals are vaccinated sooner than lower risk individuals.
  - Does vaccination decrease infectivity or severity? (We assume infectivity for now.)

The PSEAIIHRD Model



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

PSEAIIHRD Vaccination Details



$$\frac{dW}{dt} = -\frac{v_m W}{W_h + W}, \qquad v = \frac{v_m P}{W_h + W}. \tag{2}$$

- 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. $\quad W(0) = 1 - d, \quad P(0) = (1 - d)S_0$

Vaccination Rate

$$V = \frac{v_m W}{W_h + W}.$$