Submit on Crowdmark by Wednesday, August 4, 2021, 11:59pm

Instruction

Upload a PDF file with two parts. Part one should include your typed report (your discussions, data and figures). Part two should list your code. You will receive a Crowdmark link for uploading your results.

A simplified COVID-19 model

The so-called SEIR model is a standard way to model the spread of infectious diseases. It is an example of a compartmental model. We will look at this model in its most basic form, and solve it numerically for various parameters.

The population of N individuals is assigned to different compartments, and individuals can move between compartments. The SEIR model uses four compartments, S, E, I, R, representing segments of the population, so $S + E + I + R = N$ (a simplification, meaning the total population is constant, with some leeway in interpreting the term “total population”).

S. Susceptible individuals. Those are healthy, and not immune individuals who may become infected upon contact with an infected individual.

E. Exposed individuals. These are individuals who have been infected, but because of the incubation period of the virus are not yet infectious themselves. They will transition to the infected group;

I. Infected individuals. These are individuals who have been infected, and can pass on the infection to susceptible individuals.

R. Removed individuals. (In an optimistic scenario referred to as recovered individuals.) These include people who have recovered and are now immune, and people who have deceased.

Note that for Covid-19, it is still not clear yet whether recovered people are immune to the virus and its variants, and if so, by how much and for how long. This simplified model assumes they become immune to the virus and its variants. Interactions between people in compartments are proportional to the number of people in each compartment. Transfers from one compartment to another that do not involve interactions are assumed to occur proportional to the number of people in one compartment, corresponding to linear terms. The equations are as follows (the variable t is time, say measured in days):

$$\begin{aligned}
\frac{dS}{dt} &= -\beta I \frac{S}{N} && \text{susceptibles become exposed due to interaction with } I\text{, contact rate of } \beta \\
\frac{dE}{dt} &= +\beta I \frac{S}{N} - \alpha E && \text{incoming } S \text{ minus exposed moving to } I,\ \alpha = \text{ 1/incubation period} \\
\frac{dI}{dt} &= +\alpha E - \gamma I && \text{incoming exposed - “removed”},\ \gamma = \text{ 1/infectious period} \\
\frac{dR}{dt} &= +\gamma I
\end{aligned}$$

1. Implementation.
a). Write Matlab code to solve the SEIR equation. You may use the the code `SIR.m` to simulate the process or Matlab's built-in functions, for example `ode45` or `ode15s`, to solve the SEIR equations numerically.

b). Run the code with the following parameters and initial conditions for $t = 180$ days and report a plot of the S, E, I, R curves.
Parameters:
$N = 5,000,000$, roughly the number of individuals in British Columbia.
$\alpha = 1/5$, incubation period of roughly 5 days.
$\gamma = 1/10$, infectious period of 10 days. (The actual period is probably longer, but this value takes into account that sick people go to hospital or stay home, rather than continuing to circulate among the general population).
$R_0 = 2.5$; you probably have heard about this now infamous parameter R_0, the basic reproduction number, which roughly translates to the number of individuals an infected individual can transmit the virus to on average. For our model we have $R_0 = \beta/\gamma$ and thus $\beta = R_0\gamma$. (Note that the R in R_0 has nothing to do with the compartment of "removed" individuals R.)

Initial conditions:

$$R(0) = 0, \qquad I(0) = 40, \qquad E(0) = 20 \times I(0), \qquad S(0) = N - I(0) - E(0) - R(0).$$

c). With the same parameters and initial conditions in b) and assuming all infected individuals are reported and recoded (very ideal), the number of incident (new) cases on day t is given by $\alpha E(t-1)$. Plot the curve for the number of incident cases.

2. Time-dependent parameters.
a). In reality, some of these parameters will be time dependent – the effect of physical distancing and lockdown or reopening. Let $R_0 = R_0(t)$, hence, $\beta = \beta(t)$ be the time-dependent parameter. According to the model, β is the contact rate, which can be controlled. If we all stayed in a remote log cabin by ourselves, $\beta = R_0 = 0$; if we practice physical distancing and wear masks when physical distancing is not possible, then R_0 might stay below 1; if we hang out in bars or at large gatherings, then β and R_0 will go through the roof – leading to large numbers of Is, infected and infectious people.

We could model the effect of intervention (e.g. social distancing) with data for R_0 as follows (three scenarios are given):

Days (since outbreak)	1-20	21-70	71-84	85-90	91-110	111-180	after 180
R_0 (scenario one)	3.5	2.6	1.9	1.0	0.55	0.55	0.5
R_0 (scenario two)	3	2.2	0.7	0.8	1.00	0.90	0.5
R_0 (scenario three)	3	2.2	0.9	2.5	3.20	0.85	0.5

Modify the Matlab code in question 1 so they are compatible with the varying R_0.

b). Run the modified code with the other parameters unchanged as in question 1. Report the plots of S, E, I, R curves for the three scenarios. Report the plots of the curves of incident cases for the three scenarios.

3. Becoming a member of the modeling team for the infectious disease epidemic.
a). Download the case data from BCCDC at `http://www.bccdc.ca/Health-Info-Site/Documents/BCCDC_COVID19_Dashboard_Case_Details.csv`. The data include all reported cases in British Columbia, with information about reported date, health area, sex and age group of each case. We will only use the reported date. Use the data to create a scatter plot of number of incident (new) cases in British Columbia on each date. Report the plot.

b). Adjust parameters and initial conditions in the SEIR model with time-dependent R_0, so that the curve of incident cases from the model (e.g. plots in question 2.b) roughly coincides with the scatter plot of reported cases (see plot in question 3.a). Note that this needs more than 180 days and you may need to adjust all of the parameters including the time (day) interval for constant R_0, for example, instead of using 1-20 and 21-71, you may need to change the interval to 1-100 and 101-180. Report the parameters you used and the plot including the curve of incident cases from the SEIR model and the scattered points of number of reported incident cases.