# Modeling and Policy Analysis for an Epidemic

*Background*

Consider an epidemic, such as influenza, in which the disease is transmitted directly by close contact between infected people and susceptible people. We shall suppose that

- The disease lasts in an average individual about 10 days;
- After contracting the disease, it takes 3 days on the average to start showing symptoms and becoming aware one is infected, but one is infectious to others right from the start;
- There are thus four significant populations: susceptibles, infectious-but-not-symptomatic, symptomatic, and recovered;
- There are no deaths, no births, and no migration in or out of the system;
- After recovering from the disease people are immune and can not contract it again, at least over the course of the single epidemic that is to be simulated in this exercise.

*Problem*

Formulate a model of an epidemic. Capture in equations the following assumptions:

- There are four populations to distinguish, as described above.
- A susceptible person makes contact with a number of people per day. For simplicity, assume the average number of people contacted per susceptible per day is constant throughout the epidemic (5? 10? 25?).
- *Susceptible contacts per day* is defined as the number of susceptibles times the average number of people contacted per susceptible per day.
- Some fraction of the *susceptible contacts per day* is with infectious people. The *probability that a contact is infectious* is the ratio of the infectious population to the total population.
- Finally, some constant fraction of the *susceptible contacts with infectious people per day* will result in transmitting the disease. The *infection rate* is the number of susceptibles infected per day. It equals the number of *susceptible contacts with infectious people per day* times the *fraction of contacts transmitting disease*.

Assume that initially there are 9,998 susceptibles, 2 infectious-but-not symptomatic people, and no symptomatic or recovered people. Let time be in days.

*1) The Basic Epidemic Model*

After formulating a model fitting these assumptions, perform some simulations and adjust appropriate parameters to achieve a reasonable looking epidemic. How long does it take the epidemic to play itself out?

[For graphs of an epidemic, see page 3 of this assignment and Sterman, p. 301. Don't use the model given in Sterman, however. To fit the description given here, your model will be different in several important respects.]

Pick a Time Step smaller than the common rule of thumb for the Time Step [one-quarter to one-tenth the smallest time constant]. The reason for a smaller Time Step here is that the susceptible population has an *implicit* time constant that gets fairly small in the middle of the epidemic. If you have trouble with your model doing bizarre things, like populations going negative, first try making Time Step smaller.

If you still get strange results, use Vensim's strip graph to try to find the source(s). Using Vensim's spreadsheet tool to look at actual numbers the model is generating is sometimes helpful also.

If you have persistent difficulties, email me your model, and I'll see if I can help.

Hand in:

- A diagram and model listing, including comments containing English meanings, if the variable names are cryptic (single space the model listing to save paper);
- Plots showing (1) the behavior of the susceptible, infectious-but-not-symptomatic, symptomatic, and recovered populations, (2) the flows in this system, plus (3) any other variables you think it's useful or interesting to show. [In setting up a custom graph, you can put two or more adjacent variables on the same scale by checking the box(s) between the selected variables. Comparable variables should almost always be on the same scale to make visual comparison easy.]

*Model experiments and enhancements*

<u>2) Quarantine</u>

The Department of Public Health wants to test policies associated with **quarantining** people who show symptoms of the disease. We shall assume that quarantined people do not infect anyone. The infection spreads only from an "infectious population at large," which would include all those who are infectious but are not quarantined.

Add to your basic epidemic model a policy parameter (a constant) called the "fraction quarantined" (dimensionless), and reformulate your model, as required, to simulate the policy of quarantining some fraction of those who are known to have the disease. Note that the denominator of the probability that contact is with an infectious person will change with quarantining, as well as the numberator.

Simulate your reformulated model, first without any quarantine (fraction quarantined = 0) to be sure it behaves exactly as your basic epidemic model. Don't proceed until it does! Then test various quarantine policies, that is, various values of the fraction quarantined. What effects does quarantining have? Could the fraction quarantined in reality be 1? Why can't a quarantine policy prevent an influenza epidemic?

Hand in:

- A model listing with the new equations or changes highlighted;
- A Vensim diagram of your model with the new structure highlighted somehow;
- Plots showing the behavior of important variables in this system. Be selective; show the plots you regard to be significant.
- Answers to the quarantine questions in the paragraph above.

3) Inoculation

The Public Health Department also wants to test policies associated with **inoculating** some of the population during the epidemic. Assume there is a fixed inoculation capacity of say, at most 300 people per day. Note that actors in the system can not tell the difference between infected-but-not-symptomatic people and susceptible people; they would inoculate both kinds but only the susceptibles would be saved from getting the disease.

Formulate the immunization rate of susceptibles as the *inoculation rate* times the *fraction inoculated who are susceptible* (i.e., who don't already have the disease). The immunization rate subtracts from the pool of susceptible people.

The *inoculation rate* would have to be either the *inoculation capacity* or the *desired inoculation rate,* whichever is smaller. (You'll want to use the MIN function here; we can't inoculate faster than our capacity, even if there are a lot of people wanting to be inoculated. and we wouldn't innoculate if nobody wants it.) The *desired inoculation rate* would be the total pool of people waiting to be inoculated divided by the *inoculation time,* which could be set at, say, two days to capture the delays in getting inoculated.

Simulate your new model, first without any inoculation or quarantine to be sure it behaves exactly as your basic epidemic model. [You can zero out your inoculation policy by setting the inoculation capacity to zero.] Then activate the inoculation structure by setting the capacity to 300 people per day. Try two or three different values of the constant representing the inoculation capacity to test whether larger or smaller public health efforts could avert the epidemic. If you want, test also different values of the inoculation time.

Hand in a highlighted equation list and diagram, plots, and brief commentary, as outlined above.

4) Combined policies

Experiment with a combined policy of a quarantine along with an inoculation program. Show a run or two.

Briefly comment on the policy implications of your simulations.

*Typical dynamics of an epidemic*