42-302/42-782: Biomedical Engineering Systems Modeling and Analysis (Fall 2021)

Quiz 3 : Thu 2 December 2021

Instructions

1. This test is open book, open notes.
2. You may not receive assistance from others in completing this Quiz.
3. You may not submit other's work as your own.
4. You may clarify the Quiz questions with the instructor and TAs via Zoom during normal lecture time or email. **Do NOT use Piazza.**
5. Please start each problem on a new page.
6. You have **90 minutes to complete the Quiz + 20-minute grace period** to download the problem set and to upload the answers (i.e. total of 110 minutes).
7. The Quiz is set to be **available from 8 am to 6 pm EST**. You may start the Quiz at any time between the stated time period, but you must submit your answers within the given time limit of 100 minutes (counting from the start time), and before 6 pm EST.
8. Both typed up answers and scanned handwritten documents are acceptable. Please make sure that your scans have high enough resolution and your handwriting is legible.
9. For any problem that requires sketching, you may sketch directly onto the provided figure. If you cannot sketch directly on the PDF file, you may replicate the figure by hand and sketch your answer on top of it. Make sure that you label the sketch clearly.
10. Report your answer with the appropriate unit (when applicable).

11. Submit your answers as a **single PDF file on Gradescope**. **Late submission will be penalized** (see late submission policy on the syllabus).
12. Submit your **MATLAB file(s) on Canvas** (all MATLAB files that you used in this Quiz).
    Go to Canvas > Assignments > Quiz 3 MATLAB code.

There are 6 questions.

42-302/42-782 Quiz 3

1. **[Required, 2 pts]** Sign or type your full name below to acknowledge the following statement.

   Note: *If you do not have access to a printer, scanner or cannot sign/type directly on a PDF file, you may write your full name, Andrew ID and sign your signature on a piece of paper, AND indicate that they are for Q.1 in Quiz 3.*

   I pledge to uphold the highest academic standards and integrity. I affirm that I have not used any unauthorized materials in completing this exam, and have neither given assistance to others nor received assistance from others. Further, I affirm that 1) I have not observed any other students in this class acting to gain and unfair advantage, 2) if so, I have reported to my instructor any activity I have observed that is not in accordance with CMU academic integrity. I do so to sustain CMU culture of integrity, responsibility and community. I understand that there are significant consequences for violating academic integrity and that suspected violations will be reported to the School and the University. (https://www.cmu.edu/policies/student-and-student-life/academic-integrity.html).

   Full name (print): Nakya Ni

   Andrew ID: qinyun

   Electronic signature: Nakya Ni

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2. **[15 pts]** A new strain of virus causes an outbreak of hand-foot-mouth disease (HFMD) at a childcare center. The HFMD is spread by direct contact with saliva or mucus. The childcare center director wants to find the best solution to minimize disease transmission without closing the center.

   a) **[2 pts]** The first potential solution is to split children up into many small groups where children can only have direct contact with their group members. This effectively decreases the number of direct contacts among children. To simulate this effect, which **one model parameter** in the spread of disease model would you change and in which direction (lower/higher)? Explain your answer.

   Nsoc; lower. Split children into small groups means the average number that people can have direct contact with each other is small. It is represented by parameter Nsoc.

   b) **[2 pts]** Another potential solution is to schedule more frequent cleaning and disinfection. This effectively kills or weakens the virus. To simulate this effect, which **one model parameter** in the spread of disease model would you change and in which direction (lower/higher)? Explain your answer.

   Pbio. Lower. More frequent cleaning and disinfection means smaller probability of contracting disease. It is represented by parameter Pbio.

   c) **[4 pts]** The director runs simulations for different scenarios (see next page): no intervention (top figure), small groups of children (middle figure) and frequent cleaning (bottom figure). *Note that these figures are in colors.*

   From the figures, estimate how long it takes for the number of contagious cases to reach its peak for each of the three scenarios. Explain how you obtain your answers.

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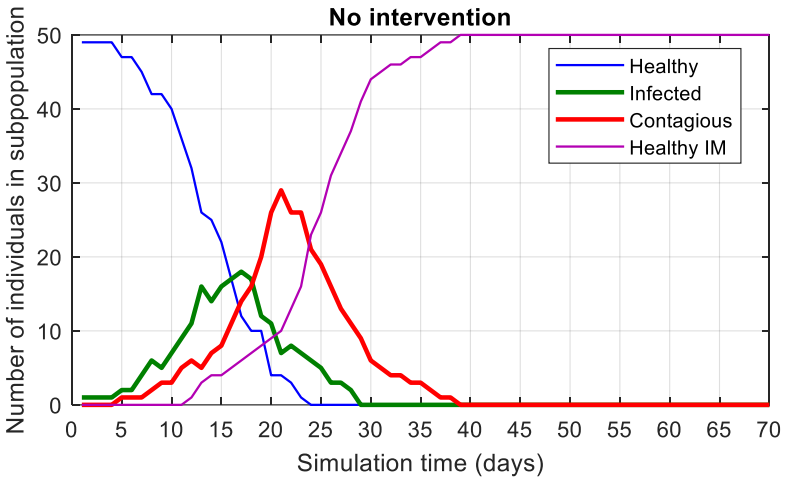
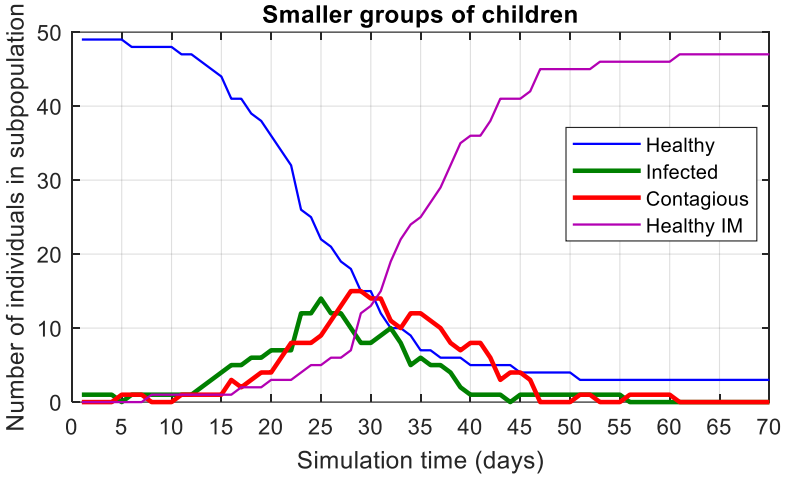
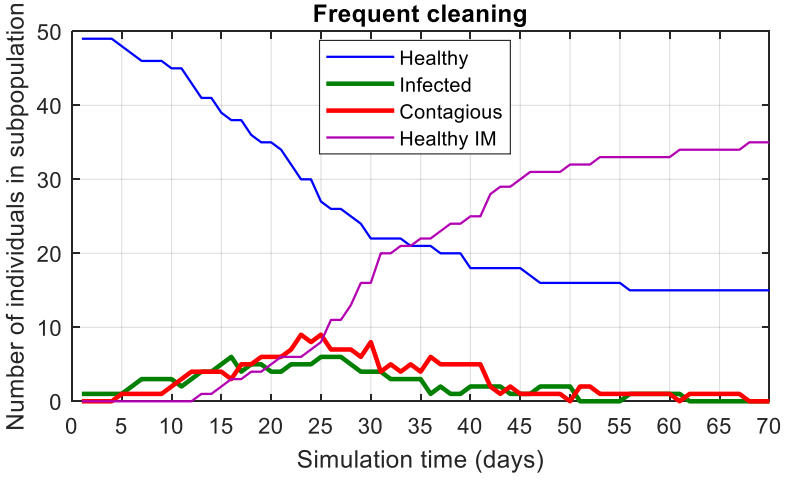
No intervention: 22.



Smaller groups of children: 27 days.



Frequent cleaning: 23 days.



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d) **[4 pts]** From the figures, estimate the number of children ever infected by this new strain of HFMD virus for each of the three scenarios. Explain how you obtain your answers.

No invention: 0. Because all children get immunity.
Small group: 0. No contagious children that can spread the disease, and also there is no infected child.
Frequent cleaning: 0. No contagious children that can spread the disease, and also there is no infected child.

e) **[3 pts]** Between the two possible solutions, which one would you recommend to the childcare center director to ensure children's safety? Explain your answer.

I will recommend Frequent cleaning. Because this solution control the number of contagious people at a lower level compared to small group, which make most children are healthy with no symptoms at the same. In this way, children center is more likely to spend more time taking care of each children.

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3. **[Total: 30 pts]** A sailor got washed up on a beach of an isolated island, inhabited by 150 islanders. The friendly islanders welcomed the stranded sailor to their island and let him stay. The sailor was sick with some contagious disease that the islanders had never been exposed to (i.e. no immunity). Assume that the day the sailor arrived on the island (day 1) was the first day that he became contagious.

   The following are the information about this disease and the community:

   - When someone contracted the disease, it took 5 – 10 days before that person showed any symptoms and could spread the disease to others. Once the sick person could transmit the disease, it took 10 – 15 days for that person to recover from sickness. Once recovered, that person could not get sick from this same disease for 100 – 200 days.
   - Assume that the average number of contacts per day was half the population size, with the standard deviation of 10% of the average number of contacts per day. If a sick and symptomatic person made contact with an unimmune individual, there was a 60% chance of disease transmission.

   a) **[2 pts]** What is the total population size for this simulation?

   151

   b) **[2 pts]** List the number of individuals in each of the following subpopulations on day 1:

      - Healthy without immunity
      - Infecte
      - Contagious
      - Healthy with immunity

   c) **[3 pts]** What are the incubation, recuperation, and immunity periods of this disease?

   Incubation: [5, 10]
   Recuperation: [10, 15]
   Immunity: [100, 200]

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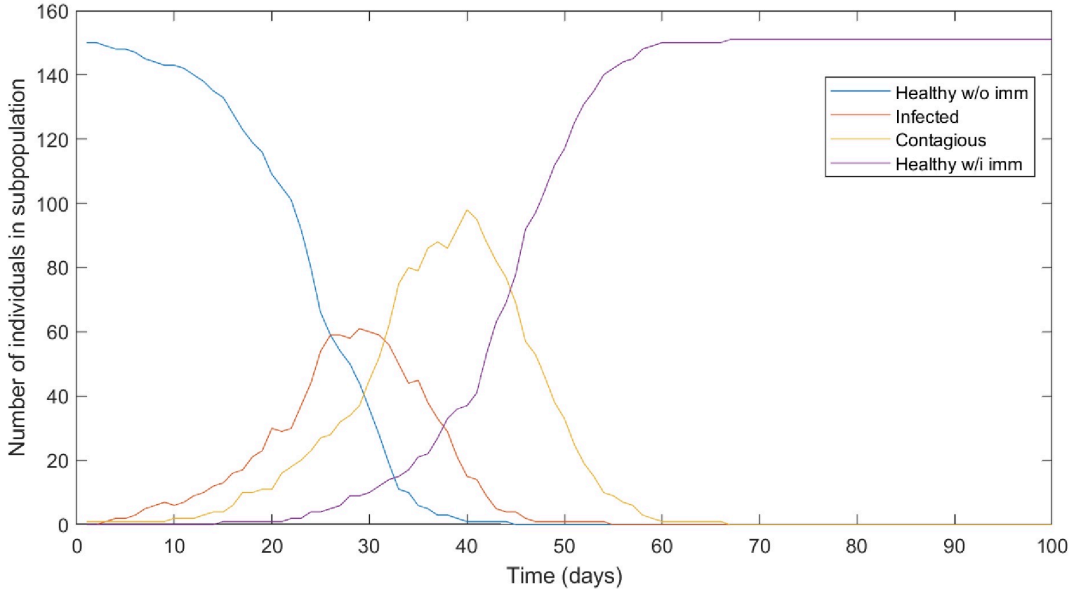
d) **[2 pts]** What are the average number of exposures per day and the associated standard deviation? State the parameters and their values.

Nsoc = 75.5;
SDsoc = 0.1*75.5=7.55;

e) **[1 pts]** What is the probability of contracting the disease upon contact? State the parameter and its value.

Pbio = 0.6;

f) **[4 pts]** Run a **single simulation for 100 days.** Assume that within these 100 days, no one else entered or left the island. Plot the number of individuals in each subpopulation vs. number of simulation days as a single plot (i.e. 4 lines in one figure). Clearly label the axes and the lines belonging to each subpopulation. **Copy and paste the plot to your solution file that you will submit on Gradescope.**



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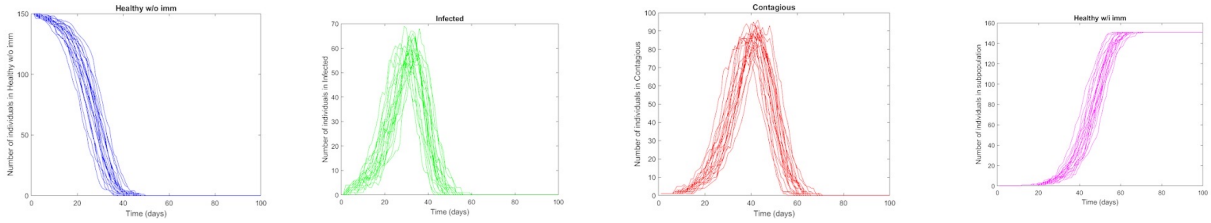
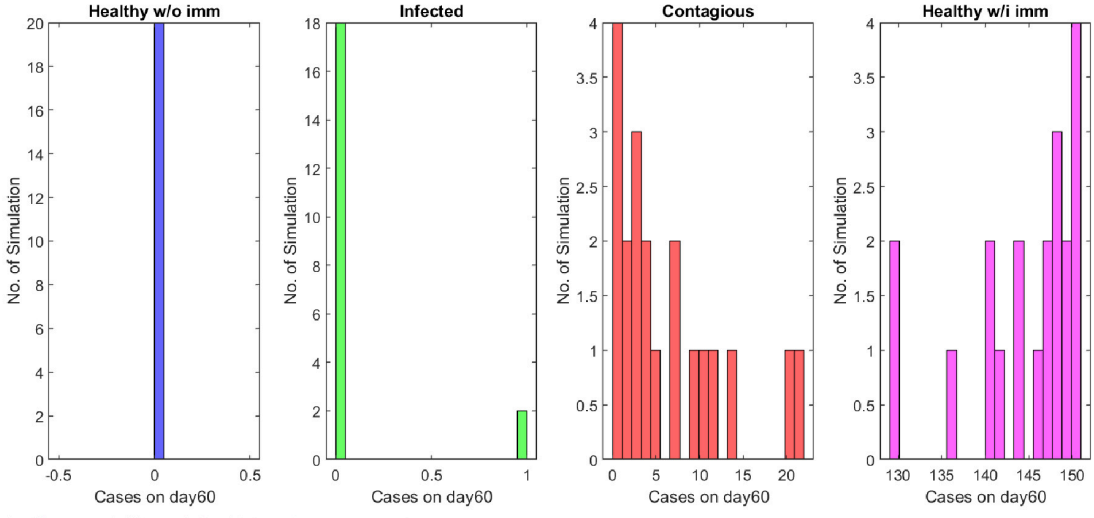
g) **[6 pts]** Run **twenty 100-day simulations** while keeping the model parameters and the initial number of individuals in each subpopulation the same for each simulation. Plot the number of individuals in each subpopulation vs. number of simulation days as a single plot. Color code your graphs (one color per subpopulation). Clearly label the axes. State which color belongs to which subpopulation (you can type/write which color represents which subpopulation if you do not know how to properly set the legend in MATLAB.) **Copy and paste the plot to your solution file that you will submit on Gradescope.**



h) **[6 pts]** Create 4 histograms, one for each subpopulation, of the number of individuals in the subpopulation on **day 60**. Set the number of bins for the histogram to **20 bins**. Clearly label the axes and label which histogram belongs to which subpopulation. **Copy and paste the histograms to your solution file that you will submit on Gradescope.**



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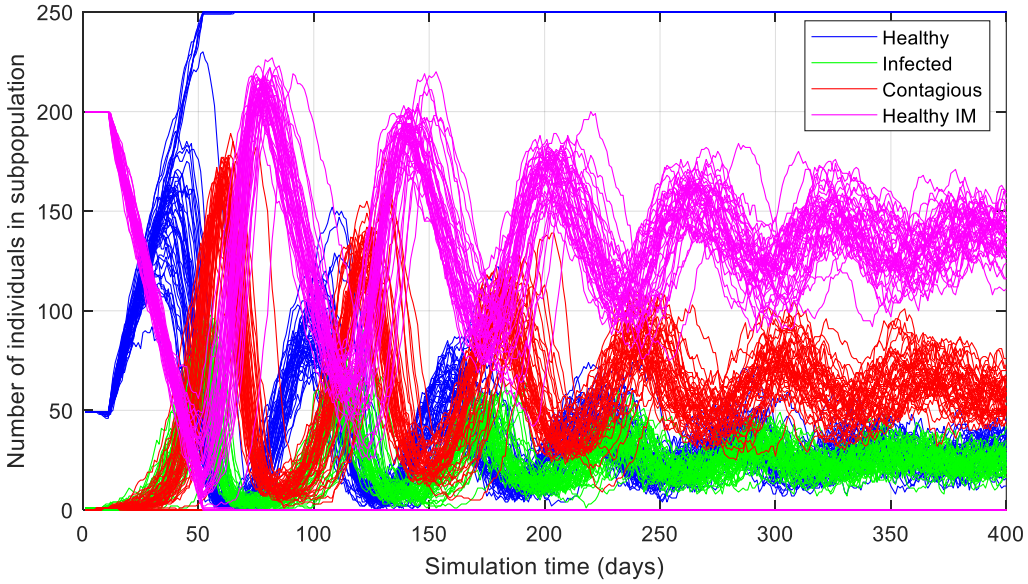
i) **[4 pts]** How many simulations out of 20 show that the **entire population was healthy at day 60**? Explain how you obtained your answer.

4 simulations. There are four simulations that 151 people are all healthy with immunity.

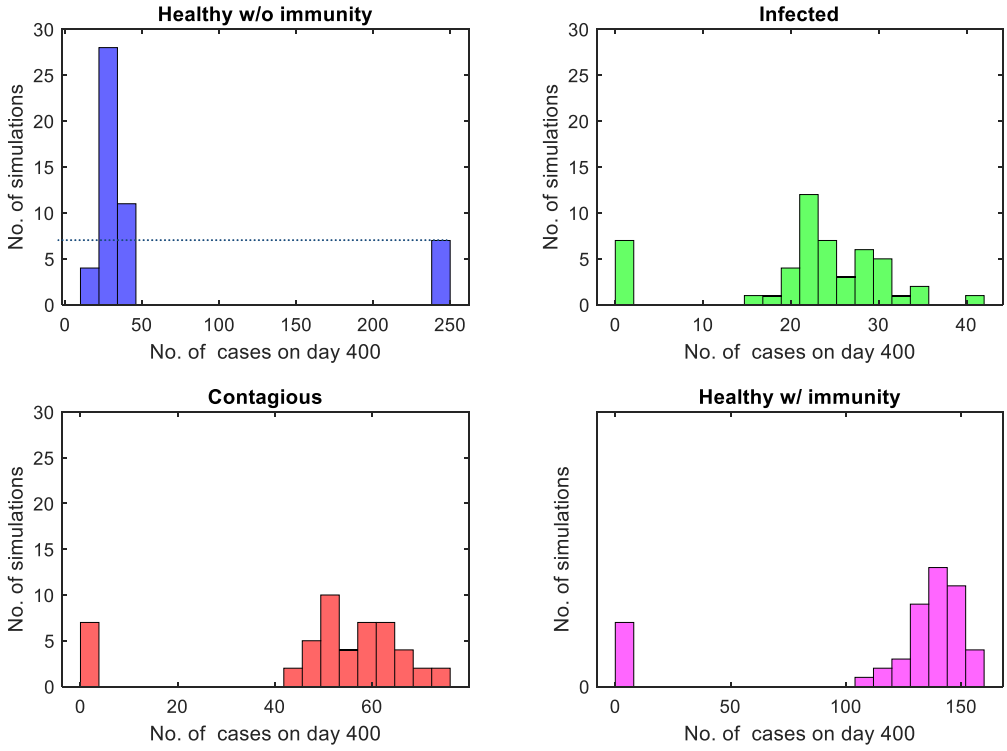
[Continues on next page]

4. **[Total: 18 pts]** A new vaccine was deployed as an effort to stop an outbreak of disease X in a small, isolated town. The figure below shows 50 simulations of the spread of disease X when a portion of the town population was vaccinated on day 1. Also on day 1, there was one infected person. Each simulation lasts for 400 days.

   Note that figures shown below are in colors.



   The histograms show the number of individuals in each subpopulation on day 400.



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The model parameters used in the simulation are:

```
Tinc = [4, 7]; %incubation period [days]
Trec = [9, 18]; %recuperation period [days]
Timm = [10, 50]; %immunity period [days]
Nsoc  = 200;
SDsoc = 20;
Pbio  = 0.4;
```

a) **[1 pt]** What is the population size of this town?

251;

b) **[1 pt]** What is the **percentage** of people in town that received vaccination on day 1?

200 people are vaccinated. The percentage is 200/251 *100% = 79.68%

c) **[4 pts]** The line graphs show that the number of individuals in each subpopulation oscillates over time. What causes the oscillations? Explain your answer.

The sub population of healthy with immunity decrease very fast at the beginning, which means the immunity period of time is short. The effect of this vaccine is short.

d) **[4 pts]** Based on these 50 simulations, what is the **chance of total disappearance** of disease X by day 400? Explain how you obtained your answer.

From the historgram figure, there are 7 simulations out of 50 simulations that all people are healthy. Therefore there is 7/50 *100% =7.14% chance that total disappearance of disease X by day 400.

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e) **[4 pts]** If all but one individual in this town were vaccinated on day 1, and the only unvaccinated person is contagious on day 1. Would this level of vaccination guarantee a complete prevention against disease X? Explain your answer. *(No simulation required)*

Yes. But not 100% sure. Because the incubation time is [10, 18], immunity period is [10, 50]. If someone contact with the contagious people when he is out of immunity period when the contagious single is still in the recuperation period. There is a small chance that the disease X will spread. In all, in this case, there is much smaller chance that the disease X will spread.

f) **[4 pts]** If you were the public health director of this town, what would you do such that, with certainty, there will be no disease X in this town after 400 days? You can choose to do anything that the simulation model permits – could be one thing or a combination of changes. However, **you may not change the model structure or introduce new parameters/variables** and there must be **at least one contagious individual on day 1**.

Describe which and how you would change the model parameters and/or the initial value in each subpopulation to simulate such intervention. *(No simulation required)*

Make everyone vaccinated thus maximize the sub population number of healthy with immunity. Frequent cleaning thus minimize the Pbio: the chance to spread the disease. Make people small group and limit the contact times, which minimize the Nsoc.

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5. **[Total: 9 pts]** Preventive measures against disease that can be spread by respiratory droplets

   a) **[3 pts]** Which model parameter would a mask mandate affect? How would you change that parameter? Explain your answer.

   Pbio. Set a smaller Pbio value. Mask reduce the chance contracting the disease.

   b) **[3 pts]** We often observe a spike in number of cases of flu and COVID-19 (both can be spread by respiratory droplets) in winter. Which model parameter would you change and how to simulate the situation in winter? Explain your answer.

   Set smaller period for Timm, larger Pbio, larger period for Trec. In winter people have weak immunity and is more likely to contract disease by respiratory droplets. Low temperature also makes the virus more active.

   c) **[3 pts]** List 3 ways you, as a member of the community, can help slow the transmission of disease that can be spread by respiratory droplets.

   1. Wearing mask to reduce the chance to contract disease by droplet.
   2. Reduce the contact times with other people.
   3. Drink more water and wear more cloth to keep warm and prevent ourselves from getting cold and fever.

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6. **[Total: 14 pts]** Given the model parameters and the initial number of individuals in each subpopulation, use the simulation model of the spread of disease in a single population to predict the number of healthy without immunity individuals, infected individuals, contagious individuals and healthy with immunity individuals from **day 1 to 10**.

   a) **[7 pts]** Spread of disease in a household of 5 members. Plot the number of individuals in each subpopulation vs. number of simulation days as a single plot (i.e. 4 lines in one figure). Clearly label the axes and the lines belonging to each subpopulation. **Copy and paste the plot to your solution file that you will submit on Gradescope.**

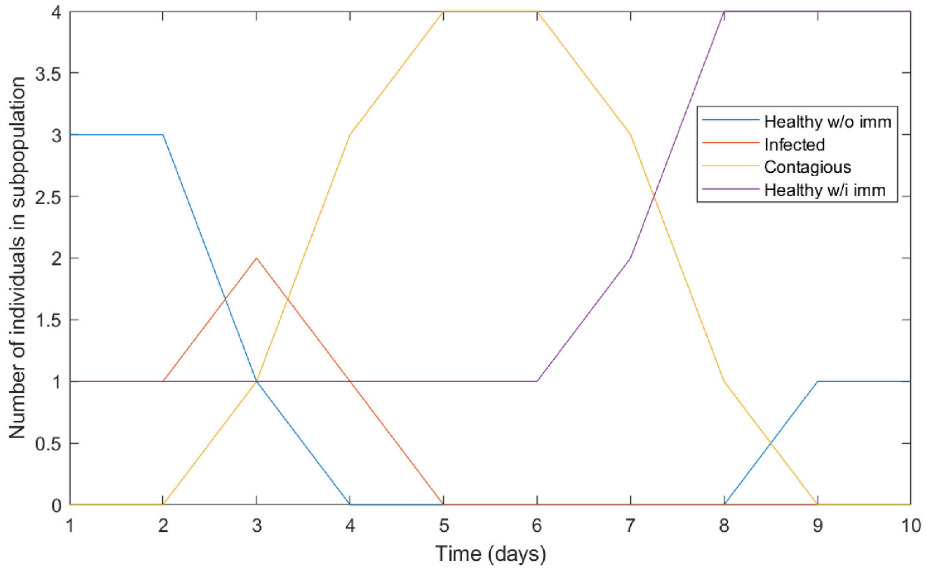
   Model parameters:
   Incubation period = 1 day
   Recuperation period = 4 days
   Immunity period = 7 days

```
Nsoc  = 5;
SDsoc = 0;
Pbio  = 1;
```

   Initial values on day 1:
   - 1 infected individual
   - 1 healthy individual with immunity

   The pairs of members (i and k) that make contact on each day:

```
i_all = [1; 2; 3; 4; 5];
k_all = [3; 4; 5; 1; 2];
```



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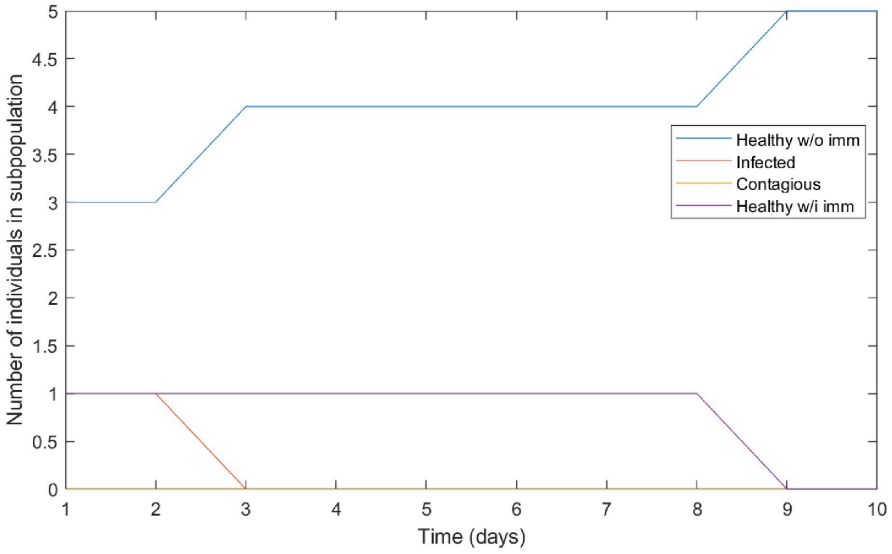
b) **[5 pts]** Change only **one model parameter** in a) to simulate the spread of **non-contagious disease** in this same household. State which **model parameter** you change and **to what value**. Plot the number of individuals in each subpopulation vs. number of simulation days as a single plot (i.e. 4 lines in one figure). Clearly label the axes and the lines belonging to each subpopulation. **Copy and paste the plot to your solution file that you will submit on Gradescope.**

Trec = [0, 0]



c) **[2 pt]** State the **MATLAB file names** that you used for

a) A single simulation

Single_sim.m

b) Multiple simulations.

multi_sim.m
Q4_q4_multi_sim.m

Deliverables:

- Submit your **answers as a single PDF file on Gradescope**.
- Submit your **MATLAB file(s) on Canvas** (all MATLAB files that you used in this Quiz). **Go to Canvas > Assignments > Quiz 3 MATLAB code.**
  You may leave the model parameters and initial values to whatever values that you last used in this Quiz.