



Modeling COVID-19 Control Measures on a Cruise Ship

INTRODUCTION

In early 2020, COVID-19 outbreaks on cruise ships captured news headlines. In this case study, you will model the spread of COVID-19 on a cruise ship using real data and the [Epidemic Simulator](#). You will consider how the SIR graphs generated by the simulator relate to what is happening onboard the ship. You will also evaluate the impact of a specific control measure, lockdown, that was used to reduce the virus's spread. These concepts and models apply to many other infectious diseases.

This case study is divided into the following parts:

- In **Part 1**, you will learn about the 2020 COVID-19 outbreak on the *Diamond Princess* cruise ship.
- In **Part 2**, you will prepare to model the outbreak by determining two key parameters: the recovery and transmission rates in the absence of control measures.
- In **Part 3**, you will model the outbreak in the absence of control measures.
- In **Part 4**, you will model the impact of lockdown (i.e., restricting passengers to their rooms)
- In the **extension**, you will model the combined impact of lockdown and isolation (i.e., removing infected passengers from the ship).

MATERIALS

- access to [Modeling Disease Spread](#) Click & Learn
- computer or mobile device that can take screenshots, download files, or print images

PROCEDURE

In this activity, you will learn about a COVID-19 outbreak on a cruise ship and answer related questions. Complete the questions in the order they are shown, as each question builds on information from the previous questions.

PART 1: THE COVID-19 OUTBREAK ON THE DIAMOND PRINCESS

The infectious disease COVID-19 is caused by the virus **SARS-CoV-2** (severe acute respiratory syndrome coronavirus 2). This virus spreads through airborne droplets, which are produced when an infected person coughs or sneezes.

One of the first known COVID-19 cruise ship outbreaks was on a ship called the *Diamond Princess*. This outbreak occurred in early 2020, when there was neither much public awareness of COVID-19 nor any COVID-19 vaccines. Figure 1 shows a map of the ship's route and the dates of some important events, which are summarized below.

On January 20, 2020, an 80-year-old passenger unknowingly infected with SARS-CoV-2 boarded the *Diamond Princess* in Yokohama, Japan. This person was the **initial case** for the outbreak on the ship, meaning that they were the first individual to acquire the disease and become infectious.

Cruise ships carry many people in confined spaces. The *Diamond Princess* had 2,645 passengers and 1,068 crew members from more than 50 countries.

1. Do you predict that an infectious disease would spread faster or slower on a cruise ship than on land? Explain your reasoning.

The initial case was on the ship for six days. After getting off the ship in Hong Kong on January 25, they developed a fever and were diagnosed with COVID-19 around February 1.

Government and health officials were notified about a potential COVID-19 outbreak on the *Diamond Princess*. When the ship returned to Yokohama on February 3, it was anchored at sea as part of a **quarantine**: a public health measure that separates potentially infected individuals from the general population for some period of time.

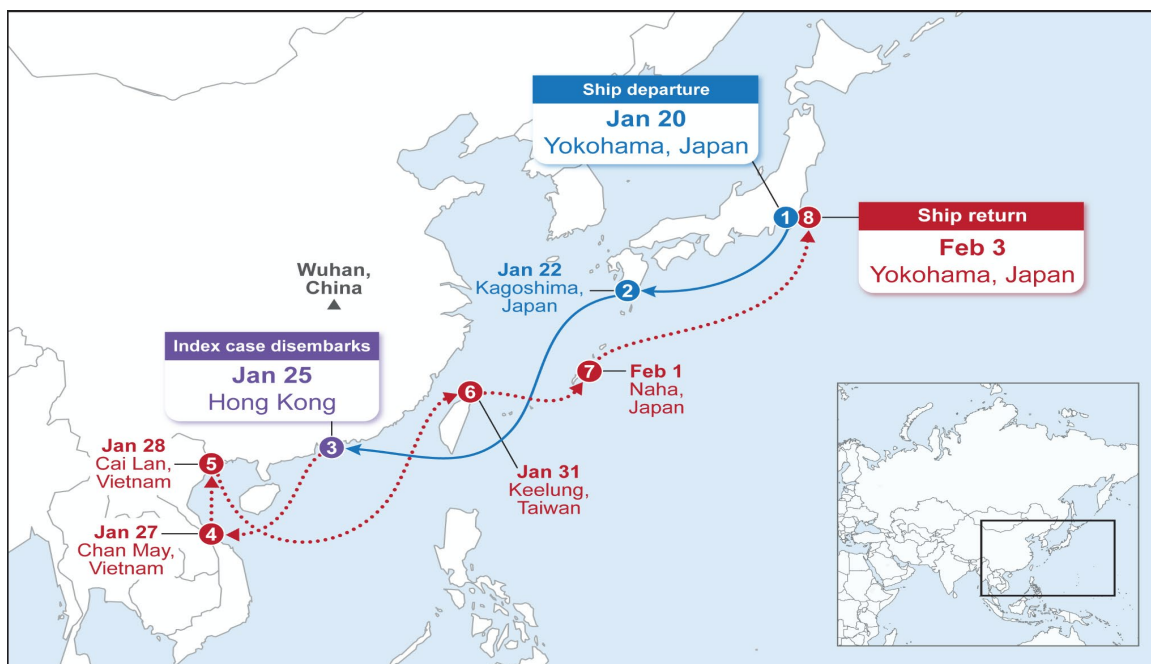


Figure 1. A map of the *Diamond Princess*'s route from January 20 to February 3, 2020 (based on Figure 1 in Nakazawa et al. 2020). The initial case boarded the ship in Yokohama and got off the ship in Hong Kong (solid arrows). The ship stopped in several countries before returning to Yokohama (dotted arrows). The major dates and events are also shown in Table 1.

Table 1. The *Diamond Princess*'s route and associated events in early 2020.

#	Date (2020)	Event
1	Jan 20	Ship departs Yokohama, Japan, with the initial case onboard
2	Jan 22	Ship arrives in Kagoshima, Japan
3	Jan 25	Initial case gets off the ship in Hong Kong
4	Jan 27	Ship arrives in Chân Mây, Vietnam
5	Jan 28	Ship arrives in Hạ Long Bay, Vietnam
6	Jan 31	Ship arrives in Keelung, Taiwan
7	Feb 1	Ship arrives in Naha, Japan
8	Feb 3	Ship returns to Yokohama, Japan

A medical team tested individuals on the ship who displayed COVID-19 symptoms or had had close contact with the initial case. They found that 61 out of the 273 tested (22%) were positive for SARS-CoV-2. On February 5, the Japanese government implemented several **control measures**, policies that aim to reduce disease spread, onboard the ship.

- Propose at least **two** control measures that could be used on the ship. Describe how each control measure might reduce the spread of the virus.

PART 2: DETERMINING SARS-COV-2 RECOVERY RATE AND TRANSMISSION RATE

In this section, you will prepare to model the spread of COVID-19 onboard the *Diamond Princess* before control measures were put in place. To learn about factors that affect disease spread, such as the **basic reproduction number (R_0)**, read the “Measuring Early Disease Spread” section in the [“Disease Spread Background”](#) tab (found in the “SIR Model Advanced” section of the *Modeling Disease Spread* Click & Learn). Then answer the questions below.

- Scientists estimated that the R_0 for SARS-CoV-2 on the *Diamond Princess* was 14.8.
 - In your own words, describe what an R_0 of 14.8 means.
 - Given this R_0 , what might happen to the people onboard the ship if no control measures were put in place? Explain the reasoning for your prediction.

The **infectious period** is the average time period (e.g., number of days) during which an infectious individual can transmit a pathogen to a susceptible individual. At the end of their infectious period, the individual is considered recovered. The **recovery rate (r)** represents the average likelihood, per day, that an infectious individual recovers. It is given as a percentage per day by the following equation:

$$r = \frac{1}{\text{infectious period (days)}} \times 100\%$$

- Scientists estimated that the infectious period for SARS-CoV-2 was 10 days.
 - Calculate the corresponding recovery rate (r) for SARS-CoV-2 as a percentage per day.
 - Describe how this recovery rate would affect the cruise ship population during the outbreak. (It may be helpful to explain what would happen to an infectious or removed individual in this case.)
 - What might happen on the ship if the infectious period for SARS-CoV-2 was 5 days instead of 10 days?

The **transmission rate** (t) represents the average likelihood, per day, that a susceptible individual becomes infected. It is related to R_0 and r through following equation:

$$t = r \times R_0$$

5. Based on an estimated R_0 of 14.8 and the recovery rate you calculated in Question 4a:
- Calculate the corresponding transmission rate (t) as a percentage per day.
 - In your own words, explain what the transmission rate that you calculated means.
 - Given this transmission rate, would you predict that the virus would spread quickly or slowly onboard the ship? Explain your reasoning.
6. In Question 2, you proposed two control measures that could reduce the spread of SARS-CoV-2. Describe whether each control measure affects the transmission rate, the recovery rate, or both. Explain your reasoning.

PART 3: MODELING COVID-19 SPREAD WITHOUT CONTROL MEASURES

You'll now model what might have happened during the *Diamond Princess* COVID-19 outbreak in the absence of control measures. To do so, go to the **Epidemic Simulator** (bottom half of the ["Simulate an Epidemic"](#) tab in the "SIR Model Advanced" section) of the Click & Learn and enter the following settings:

- Total Days: 60
- Transmission Rate (t): *your answer to Question 5a*
- Recovery Rate (r): *your answer to Question 4a*
- Initial Susceptible Population: 3712
- Initial Infected Population: 1
- Initial Removed Population: 0

Select "Simulate" to start the simulation. The SIR graph will automatically appear in the "Results" section.

7. Following the guidance of your instructor, download, print, or sketch an image of your graph. Label it as **"No Control Measures."** Make sure to include your graph when submitting this handout, in whichever format your instructor asks for.

8. Examine the relationship among the three curves (susceptible, infectious, removed) in the graph.
- The susceptible curve should decrease over time. What happens to individuals who leave the susceptible group? (In other words, which group do they move into?)
 - The removed curve should increase over time. Where do new individuals in the removed group come from?
 - The infectious curve should increase, then decrease. Where do new individuals in the infectious group come from, and what happens to them once they leave the infectious group?

Review the [“Summary”](#) section under “SIR Model Basics,” which has more information about the SIR graph. The illustration in the “Analyzing and Interpreting an SIR Graph” section shows how different parts of the graph relate to the main stages of an outbreak.

9. Use these instructions to complete Table 2.
- For the “Peak” day, record the day with the greatest number of infectious individuals.
 - In the “Peak” column, record the number of individuals in each group for the day that you selected. (You can hover over points on the SIR graph in the simulator to display the number of individuals.)
 - Skip the “Corrected Values” column for now. You will come back to it in Question 10c.

Table 2. Data for the model with no control measures at peak infection.

Groups	Peak Day _____	Corrected Values (Question 10c)
Susceptible (S)		
Infectious (I)		
Removed (R)		

10. Use Table 2 to answer the following questions:
- How many individuals had been infected by the day of peak infection (i.e., those currently infected, plus those who were previously infected and recovered)?
 - How many individuals were susceptible at peak infection? How would you interpret this value?
 - Based on your answer to Part b, how might you “correct” the values in Table 2? Fill in the last column of Table 2 with your proposed corrections.

Figure 2 and Table 3 show the timeline of events that took place on the *Diamond Princess*.

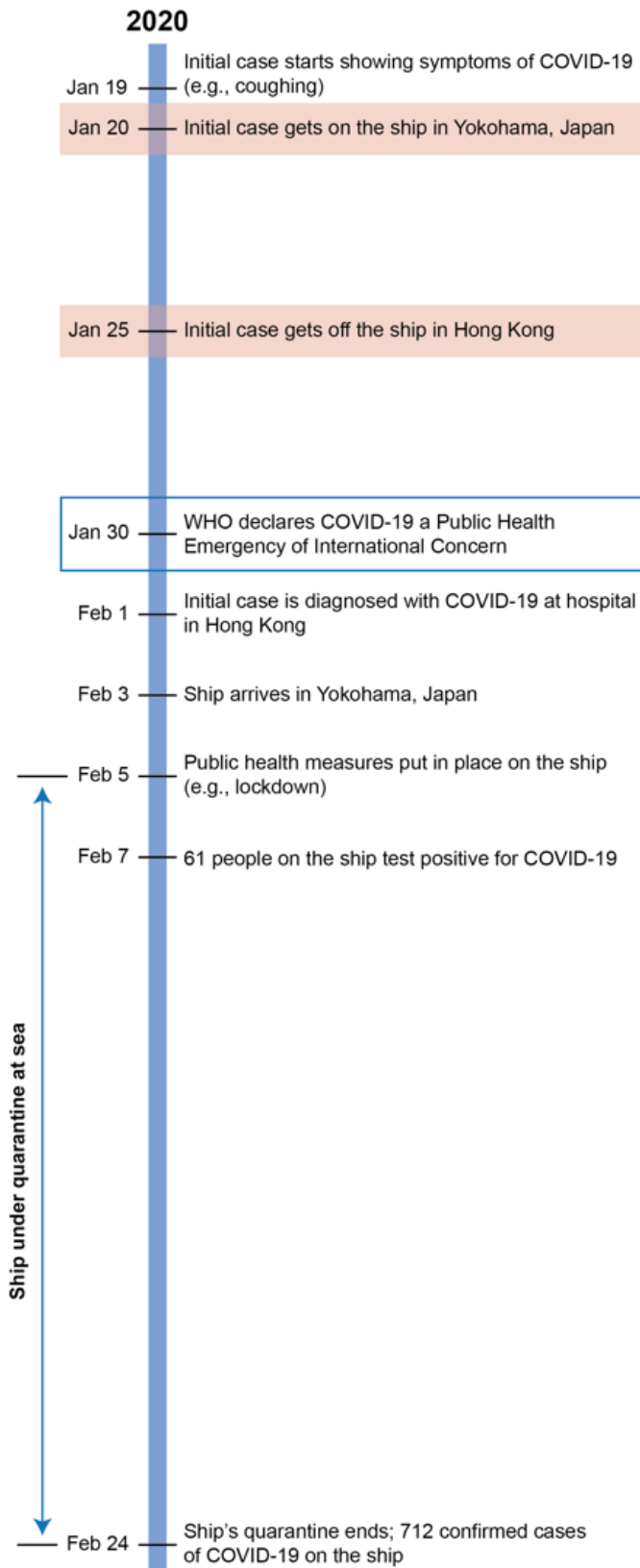


Figure 2. Visual timeline of the events associated with the *Diamond Princess* COVID-19 outbreak. The abbreviation WHO stands for the World Health Organization. This information is also shown in Table 3.

Table 3. Timeline of the events associated with the *Diamond Princess* COVID-19 outbreak. Day numbers are relative to the start of the outbreak.

Day #	Date (2020)	Event
-1	Jan 19	Initial case starts showing symptoms of COVID-19 (e.g., coughing)
0	Jan 20	Initial case gets on the ship in Yokohama, Japan
5	Jan 25	Initial case gets off the ship in Hong Kong
10	Jan 30	WHO declares COVID-19 a Public Health Emergency of International Concern
12	Feb 1	Initial case is diagnosed with COVID-19 at hospital in Hong Kong
14	Feb 3	Ship arrives in Yokohama, Japan
16	Feb 5	Public health control measures put in place on the ship (e.g., lockdown)
16–35	Feb 5–24	Ship under quarantine at sea
18	Feb 7	61 people on the ship test positive for COVID-19
35	Feb 24	Ship’s quarantine ends; 712 confirmed cases of COVID-19 on the ship

11. Compare the results of your model without control measures (as shown in Table 2 and your graph in Question 7) to the real outbreak (as summarized in Figure 2 and Table 3).
 - a. Describe one similarity and one difference between the model and the real outbreak.
 - b. During the real outbreak, 61 passengers tested positive for COVID-19 on February 7, 18 days after the initial case got on the ship. Did the model show a similar number of infected individuals on Day 18?

12. On February 24, 2020 — 35 days after the initial case got on the ship — the Japanese government ended the ship’s quarantine and allowed everyone onboard to leave. This day corresponds to Day 35 in the model.
 - a. Using your SIR graph from Question 7, complete the “End of Quarantine” column in the following table. (Remember that you can hover over points on the SIR graph in the simulator to display the number of individuals.)

Table 4. Data for the model with no control measures at end of quarantine.

Groups	End of Quarantine Day 35
Susceptible (S)	
Infectious (I)	
Removed (R)	

- b. How many individuals on the ship had been infected by the end of the quarantine (i.e., those currently infected, plus those who were previously infected and recovered)?
 - c. There were 712 confirmed cases of COVID-19 on the ship by the end of the quarantine. How does this outcome compare to your model?
13. What may account for the differences you observed between the real outbreak and the model with no control measures?

PART 4: MODELING THE IMPACT OF LOCKDOWN

Once Japanese government and health officials confirmed that a COVID-19 outbreak was occurring on the *Diamond Princess*, they put control measures in place to reduce the spread of the virus. One of these control measures was **lockdown**: in this case, restricting the ship's passengers to their individual rooms to limit their interactions. (At the time, COVID-19 vaccines had not yet been developed.) As shown in Figure 2 and Table 3, passengers were under lockdown from February 5–24 (Days 16–35 of the outbreak).

14. Scientists estimated that lockdown reduced the transmission rate of the virus by 70%. Using this information and the transmission rate you calculated in Question 5a, calculate the estimated transmission rate under lockdown.
15. Predict how the transmission rate you calculated in Question 14 would affect the spread of the virus on the ship. (It may be helpful to explain what might happen to a susceptible, infectious, or removed person with this transmission rate.)
16. Consider how lockdown could impact the model — in particular, the three curves (susceptible, infectious, and removed) in the SIR graph.
- a. Briefly describe, or draw directly on your graph from Question 7, how each curve might change if you implemented lockdown. For example, would some curves shift to the right/left, up/down, or not at all?
 - b. Explain your reasoning for the change you predicted.

17. The following settings are for when lockdown is put in place.

- Total Days: 60
- Transmission Rate (t): *your answer to Question 14*
- Recovery Rate (r): *your answer to Question 4a*
- Initial Susceptible Population: 3712
- Initial Infected Population: 1
- Initial Removed Population: 0

Enter these settings into the Epidemic Simulator, then start the simulation to generate a new graph. Following the guidance of your instructor, download, print, or sketch an image of your graph. **Label it as “Lockdown.”** Make sure to include your graph when submitting this handout, in whichever format your instructor asks for.

18. How does this graph compare to what you predicted in Questions 15 and 16?

19. Compare your SIR graph for *lockdown* (Question 17) with your previous SIR graph for *no control measures* (Question 7).

- a. How do the curves in these two graphs differ? (Compare the timelines and number of people in each group.)

- b. You may have heard that implementing control measures like lockdowns can help “flatten the curve.” Which curve is being “flattened,” and why might this be desirable?

20. Complete Table 5 using similar instructions as in Question 9.

Table 5. Data for the model with lockdown at peak infection.

Groups	Peak Day _____
Susceptible (S)	
Infectious (I)	
Removed (R)	

21. Use Table 2 (data for the model with *no control measures*) and Table 5 (data for the model with *lockdown*) to answer the following questions:

- a. How does the day of peak infection differ between the model *with no control measures* versus the model with *lockdown*?

- b. At peak infection, how does the number of infected individuals (i.e., those currently infected, plus those who were previously infected and recovered)

- c. At peak infection, how does the number of susceptible individuals compare between the model *with no control measures* versus the model *with lockdown*?

22. Let's compare the results of both models on the same day — specifically, the day of peak infection in the model *with no control measures*.

- a. Use these instructions to complete Table 6:
 - In the first row, record the day of peak infection in the model with *no control measures* (same as the "Peak" day in Table 2).
 - In the "No control measures" column, record the number of individuals in each group on that day (same as in the "Corrected Values" column for Table 2).
 - In the "Lockdown" column, record the number of individuals in each group for the model with *lockdown* on that same day.

Table 6. Comparison of the models *with no control measures* and *with lockdown*.

Day _____ (peak infection for model with <i>no control measures</i>)		
Groups	No control measures	Lockdown
Susceptible (S)		
Infectious (I)		
Removed (R)		

- b. Compare the number of infected and susceptible individuals on that day for these two models. How do they differ?

- c. Based on these models, was lockdown an effective control measure? Use evidence to support your reasoning.

23. Compare the results of the model with lockdown (as shown in Table 5 and your graph in Question 17) to data from the real outbreak (as summarized in Figure 2 and Table 3).
- Describe one similarity and one difference between the model and the real outbreak.
 - During the real outbreak, 61 passengers tested positive for COVID-19, 18 days after the index case boarded the ship. Did the model show a similar number of infected individuals on Day 18?

24. Remember that the ship’s quarantine ended on Day 35.

- Using your SIR graph from Question 17, complete the “End of Quarantine” column in the following table.

Table 7. Data for the model with lockdown at end of quarantine.

Groups	End of Quarantine Day 35
Susceptible (S)	
Infectious (I)	
Removed (R)	

- How many individuals on the ship had been infected by the end of the quarantine (i.e., those currently infected, plus those who were previously infected and recovered)?
 - There were 712 confirmed cases of COVID-19 on the ship by the end of the quarantine. How does this outcome compare to your model?
25. What may account for the differences you observed between the real outbreak and the model with lockdown?
26. During the real outbreak, control measures were implemented approximately two weeks after the initial case boarded the ship.
- How could the timing of control measure implementation affect the spread of the virus on the ship?
 - In the model with lockdown, when are control measures implemented?

- c. Based only on timing of control measure implementation, would you have expected more disease spread in the lockdown model or the real outbreak? What might explain the differences between your expectations and reality?
27. Return to the Epidemic Simulator with the same settings as in Question 17, the model with lockdown. In the simulator, R_0 is automatically calculated and displayed below the SIR graph.
- a. What is the R_0 value when lockdown is implemented?
- b. In your own words, describe what this R_0 value means.
- c. How does this R_0 value compare to the estimated R_0 value when no control measures are in place (Question 3)?
28. What's the overall impact of implementing lockdown on the ship? In other words, does lockdown protect the susceptible population? Consider the number of susceptible individuals left in the population in Tables 2 and 5.
29. What other control measures could we use today to reduce the spread of the virus in a confined location, such as a cruise ship?
30. Think about using lockdown as a control measure in society in general, not just on a ship. In your opinion, would the costs of implementing lockdown (for example, restricting people's movement) outweigh the benefits? Use evidence to justify your response.

EXTENSION: MODELING THE IMPACT OF LOCKDOWN AND ISOLATION

In real life, multiple control measures were used to reduce the spread of SARS-CoV-2 onboard the *Diamond Princess*. So far, you've examined the impact of one control measure: lockdown. Now let's examine the impact of implementing two control measures at the same time: lockdown and isolation. For **isolation**, identified infected passengers were removed from the ship and relocated to COVID-19-designated hospitals in Japan.

31. Is there a benefit to removing infectious passengers from the ship? Explain your reasoning.

One way to model isolation is to change the recovery rate. On average, individuals infected with SARS-CoV-2 take 10 days to recover, resulting in a recovery rate of 10% per day. For the isolation control measure, infected individuals were removed from the ship in four days on average. We can represent this with a recovery rate of 25% per day.

32. Explain how increasing the recovery rate can simulate the effects of the isolation control measure (removing infectious individuals from the ship).
33. Consider how both lockdown and isolation together could impact the model — in particular, the three curves (susceptible, infectious, and removed) in the SIR graph — compared to lockdown alone.
- Briefly describe, or draw directly on your graph from Question 17, how each curve might change if you implemented both lockdown and isolation. For example, would some curves shift to the right/left, up/down, or not at all?
 - Explain your reasoning for the change you predicted.
34. The following settings are for when both lockdown and isolation are put in place. The transmission rate represents the effects of lockdown, and the recovery rate represents the effects of isolation (infectious individuals removed from the ship in four days on average).
- Total Days: 90
 - Transmission Rate (t): *your answer to Question 14*
 - Recovery Rate (r): 25%
 - Initial Susceptible Population: 3712
 - Initial Infected Population: 1
 - Initial Removed Population: 0

Enter these settings into the Epidemic Simulator, then start the simulation to generate a new graph. Following the guidance of your instructor, download, print, or sketch an image of your graph. **Label it as “Lockdown and Isolation.”** Make sure to include your graph when submitting this handout, in whichever format your instructor asks for.

35. How does this graph compare to what you predicted in Question 33a?
36. Compare your SIR graph for *both lockdown and isolation* (Question 34) with your previous SIR graph for *lockdown only* (Question 17). How do the curves in these two graphs differ? (Compare the timelines and number of people in each group.)

37. Answer the following questions regarding the population makeup at peak infection. For the model with *both lockdown and isolation*, refer to your results in the Epidemic Simulator. For the model with *lockdown only*, refer to your previous results in Table 5.
- How many days did it take to reach peak infection in the model with *both lockdown and isolation*?
 - How does the day of peak infection differ between the model with *lockdown* versus the model with *both lockdown and isolation*?
 - At peak infection, how does the number of infected individuals (i.e., those currently infected, plus those who were previously infected and recovered) compare between the model with *lockdown* versus the model with *both lockdown and isolation*?
 - At peak infection, how does the number of susceptible individuals compare between the model *with lockdown* versus the model with *both lockdown and isolation*?
38. Let's compare the results of both models on the same day — specifically, the day of peak infection in the model with *lockdown* only.
- Use these instructions to complete Table 8:
 - In the first row, record the day of peak infection in the model with *lockdown* only (same as in Table 5).
 - In the "Lockdown" column, record the number of individuals in each group on that day (same as in the "Peak" column for Table 5).
 - In the "Lockdown and Isolation" column, record the number of individuals in each group for the model with *both lockdown and isolation* on that same day.

Table 8. Comparison of the models *with lockdown* and with *both lockdown and isolation*.

Day _____ (peak infection for <i>lockdown</i> model)		
Groups	Lockdown	Lockdown and Isolation
Susceptible (S)		
Infectious (I)		
Removed (R)		

- b. Compare the number of infected and susceptible individuals on that day for these two models. How do they differ?
 - c. Based on your models, were both lockdown and isolation together more effective than lockdown alone? Use evidence to support your reasoning.
39. Compare the results of your model (as shown in Table 8 and your graph in Question 34) to the data from the real outbreak (as summarized in Figure 2 and Table 3). During the real outbreak, 61 passengers tested positive for SARS-CoV-2, 18 days after the initial case boarded the ship.
- a. Did the model show a similar number of infected individuals on Day 18?
 - b. There were 712 confirmed cases of COVID-19 on the ship by the end of the quarantine. How does this outcome compare to your model?
40. In Table 9, record the results at the end of the quarantine (Day 35) for each of the three models. You can use the number of susceptible and infected individuals that you previously recorded in Table 3 for the model with *no control measures* and in Table 7 for the model with *lockdown*. For the model with *both lockdown and isolation*, refer to your graph from Question 34.

Table 9. Comparisons of the three models at the end of quarantine (Day 35).

Model	Transmission rate	Recovery rate	# Susceptible on Day 35	# Infected (Infectious + Removed) on Day 35
No control measures (Table 3)	148	10		
Lockdown (Table 7)	44.4	10		
Lockdown and isolation (Extension)	44.4	25		

41. Answer the following questions based on Table 9.

- a. What’s the overall impact of implementing both lockdown and isolation on the ship? In other words, do these control measures protect the susceptible population?

- b. Is there a benefit to implementing more than one control measure? Use evidence from the models to support your response.

42. Examine potential disease spread based on R_0 in the three models (no control measures, lockdown only, both lockdown and isolation). The R_0 value for the model without control measures has been provided in the first row of Table 8.

- a. Complete Table 10 with the R_0 values (on Day 0) for the model *with lockdown* (Question 27a in Part 4) and the model with *both lockdown and isolation*.

Table 10. R_0 values on Day 0 for the three models.

Model	R_0 on Day 0
No control measures	14.8
Lockdown	
Lockdown and isolation	

- b. How do the R_0 values in these three models differ?

- c. What do these differences indicate about the effects of the control measures?

43. All the people on the *Diamond Princess* were allowed to leave on Day 35. Some of these people may still have been infectious. Propose at least **two** control measures that infectious individuals leaving the ship could personally implement to reduce the spread of the virus to their communities.