ISYE 6644- Simulation Project Final Report

Simulation of surface (fomite) transmission of Coronavirus for indoor fitness centers

Project Group 140

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1. Abstract

The risk of surface (fomite) transmission is a potential concern for Covid's spreading patterns. In this project, we create a simulation model with around 1,000 arrivals to analyze a virtual fitness center having 5 fixed equipment, which may get contaminated by infected visitors. Once the equipment is contaminated, it would have the probability of infecting the next healthy visitor. The probability of getting infected also depends on whether a visitor is fully vaccinated or not.

To prevent surface transmission, we assume the fitness center conducts regular disinfection under different assumptions. Or they can choose to completely rely on vaccination and not to do regular disinfection. By applying this model, we find regular disinfection performs very well in reducing the infection of Coronavirus.

2. Problem Statement

In 2020, the spreading of Covid-19 viruses has become one of the most serious flu pandemics in the world. It has higher fatality ratios and infected people might become severely ill. To prevent mass infection, people are forced to keep social distances and wear masks. Droplet infection is not the only way of virus transmission. Surface (fomite) transmission may also be one of the ways of transmission. People can get infected through contact with contaminated surfaces that someone coughed on or touched.

The CDC data show that the virus can survive on non-porous surfaces for 72 hours such as stainless steel, plastic, and glasses. These surfaces or objects are common in our daily life such as door handles, elevator buttons, and tables. If infected people contaminate a certain surface and object, more people could get infected by touching the surfaces and getting exposed to viruses. It becomes another way of spreading viruses in the places where social interaction occurs. There are many different types of social interactions that speed up the spread of flu, such as commuting by bus and subways, eating in restaurants, watching sports games, or working out in the fitness centers. To mitigate the risk of surface transmission, the government keeps encouraging business owners to disinfect their places regularly.

Among those spaces, we are particularly interested in how the pandemic flu spreads in gyms or fitness centers. When the pandemic began, the gym and fitness centers were listed as the high-risk of transmission places. Visitors tend to use training equipment in particular orders and the infected ones may leave the virus on the equipment for a certain period. It may cause another person to get infected by touching that equipment and contacting the left virus.

This rule doesn’t only apply to gyms or fitness centers. Any public area can be a similar case, but gyms can be a good research topic thanks to their closed and indoor environments. This feature creates a unique spreading pattern. It interests us to conduct further research on it.

In this project, we will explore the unique simulation model of flu spreading for gym spaces. We would like to understand how the entities and processes interact with each other. Currently, the proportion of Covid-19 infections through surface transmission is still not clear. We will build a model simulating the indoor environments of fitness centers to study the spreading patterns and infections through the surface (fomite) transmission.

By introducing randomness and scenario settings, the model should be capable of simulating real-world events and exploring the possibility of reopening the gym business to the public if visitors have sufficient preventive measures like hand disinfection, getting vaccinated, or wearing masks. On the other hand, the gym can also take actions to mitigate the risks, including limiting capacity, regular sanitizations, and so on.

3. Objectives and Planning

In this project, we are studying the spreading patterns of surface transmission of the flu virus and preventive measures’ impact on stopping transmission in the gym setting. Gyms and fitness centers are useful for us to study the virus' indoor spreading patterns because we can control most of the variables in a closed environment. We would like to use this case to explore the possibility of reopening public areas by implementing sanitary measures, vaccinations, and so on.

Our goal is to quantify the effects of preventive measures on the surface transmission of the Covid-19 virus by simulating interactions between visitors and training equipment in gyms. The environments will be dynamic with 900-1,000 people variously arriving, interacting, and leaving with entities having different attributes such as immunity, infectivity, interactions frequency to change the infection rate, and spreading patterns in the gym settings while we assume all the visitors wear masks in this model. It’s because we want to focus on surface transmission by controlling the possibility of droplet infection.

Currently, most places require people to wear masks and get vaccinated if they want to enter public spaces, which greatly reduces droplet infection. However, surface transmission may be a potential concern to study if the viruses have other variants that excel at surface transmission.

In this model, visitors will arrive at the fitness centers, do their training, and leave. Visitors will have random lengths of training. Those visitors are also randomly infected with viruses before their arrival and each user will randomly interact with different numbers of fitness equipment for their training purposes. The fitness equipment is the fixed group of objects in the gym and can be contaminated by visitors and transmit viruses to another person to infect him. Furthermore, healthy visitors can get infected during the interactions and contaminate the other clean equipment afterward. Figure 1 describes the concept of each visitor's journey in this simulation model.

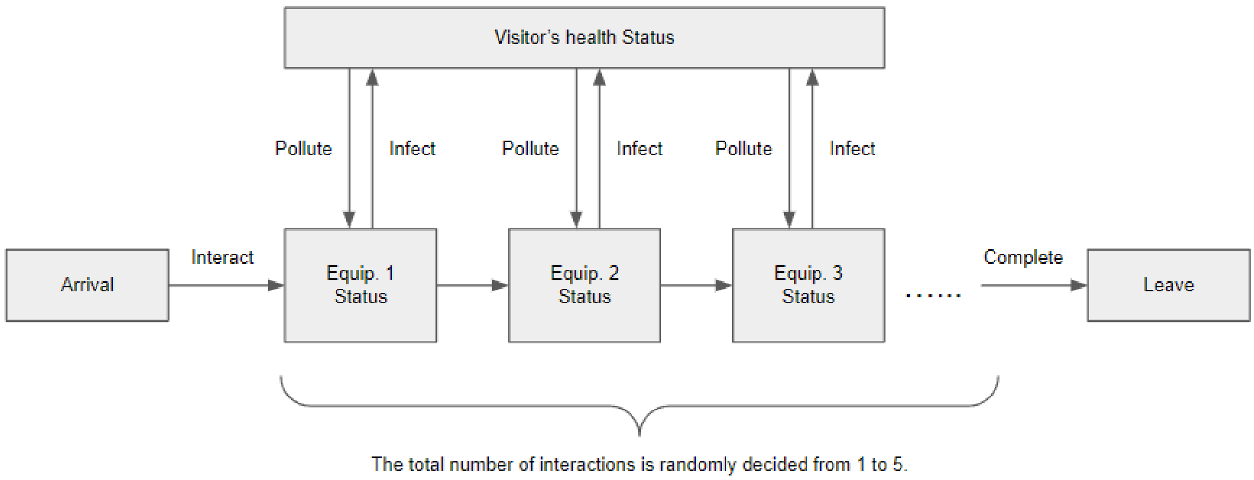

Figure 1. Visitor's Journey through the fitness center

By simulating different scenarios, we will explore and quantify the effects of actions suggested by the governments. We will introduce preventive measures into the models. For example, the virtual gym in the model may do nothing, conduct regular sanitizations to disinfect their equipment to reduce infection risks. We believe the surface transmission is still a potential risk for people to get infected even if they wear masks and most people get vaccinated.

We would like to use the fitness center case to understand the spreading patterns of surface transmission through this project, simulating the visitors' arrival, interactions, and contamination on surfaces or objects. Finally, we will evaluate the reopening possibility under the assumption that a certain percentage of visitors get vaccinated, regular sanitization by fitness centers, or more preventative measures to obtain a broader picture of the virus spreading patterns through surface transmission.

4. Methodologies

We will use Arena Simulation Software to model the risk of transmission of an infected visitor entering a fitness center open 24/7 under different potential risk mitigation scenarios. The replication length is 30 days by implementing a stochastic simulation to understand the spread of the virus in a gym. The following process flow (Figure 2) describes each visitor's journey through the virtual fitness center.

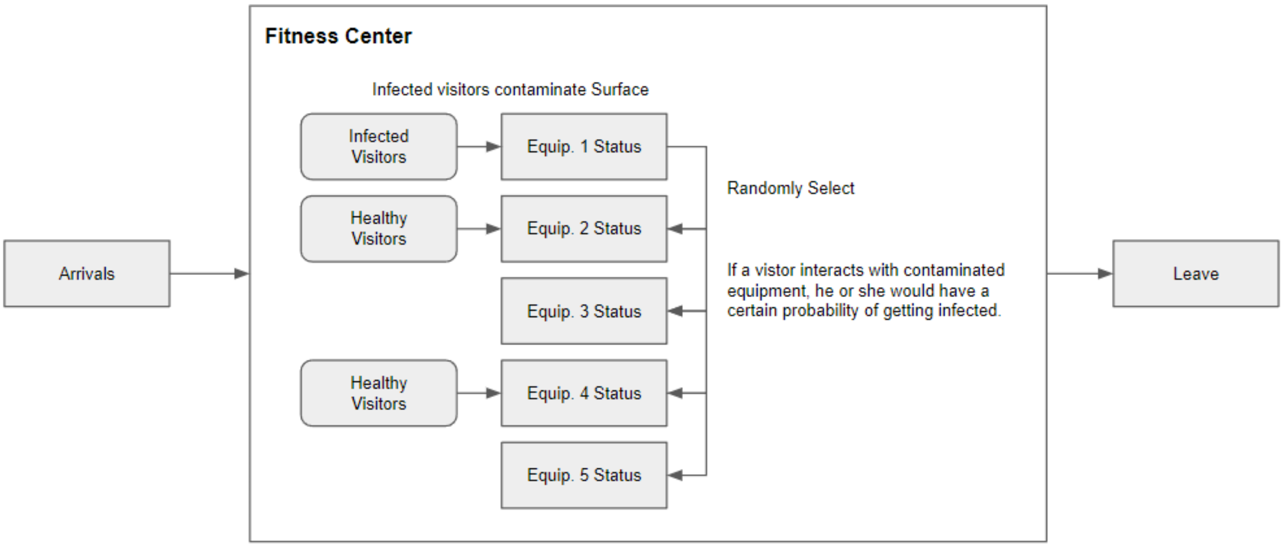

Figure 2. Simulation Process Concept

In the first place, the model generates a Poisson process to create arrivals of visitors. The simulation model begins with 5 fixed sub-models, representing the fitness equipment such as treadmill, Spinning bike, Chest press machine, and so on. Besides, we define the model elements in table 1 for simulation purposes.

Table 1. Model Elements

Name	Type	Definition	Initial Value
Visitor	Entity	Visitors who interact in the system	NA
Fitness Center	Entity	Trigger regular disinfection events	NA
Health Status	Attribute	Visitors (Entity) Health Status	0
Equip.1 Status	Variable	0 is clean and 1 is contaminated	0
Equip.2 Status	Variable	0 is clean and 1 is contaminated	0
Equip.3 Status	Variable	0 is clean and 1 is contaminated	0
Equip.4 Status	Variable	0 is clean and 1 is contaminated	0
Equip.5 Status	Variable	0 is clean and 1 is contaminated	0

Visitors arrive at the fitness center to work out with the fitness equipment. They will have three types of health status, including health but unvaccinated, health and vaccinated, and infected. They randomly decide their length of work-out, ranging from 1 to 5, which is the total number of fitness equipment they will use during their customer journey. The sequence of picking up which fitness equipment to use will also be random. The service time for each training is determined by exponential distributions. The following Arena screenshot shows the framework of the simulation model:

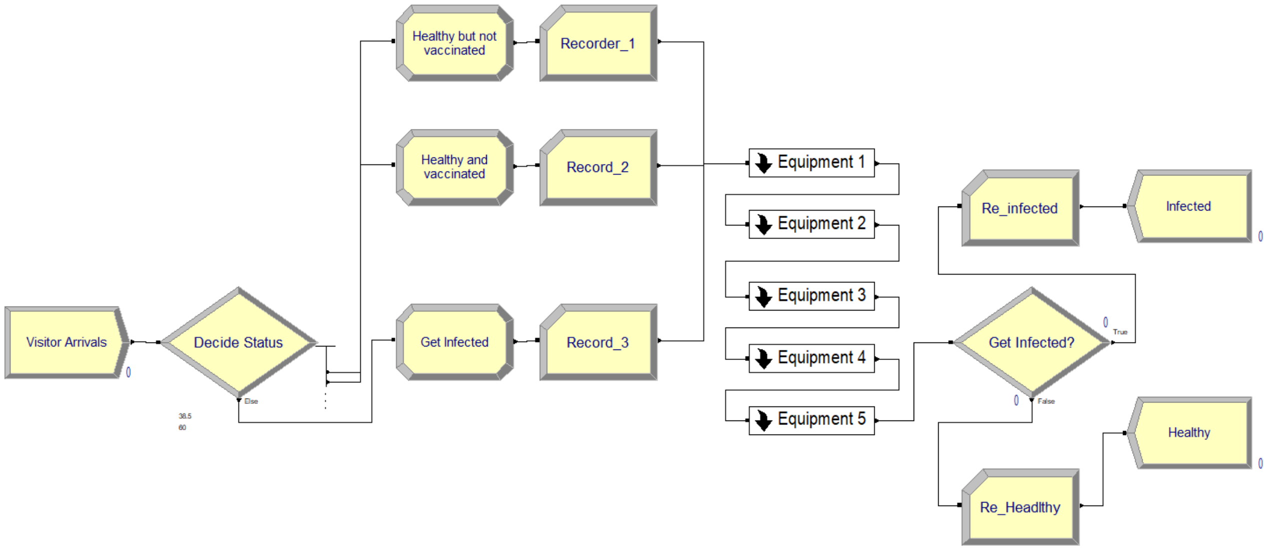

Figure 3. Arena Simulation Overview

As you can see in the above framework, the model has 1 top-level and 5 sub-models. The 1 top model generates visitors' arrivals and assigns three statuses to those visitors as healthy but unvaccinated (38.5%), health and vaccinated (60%), and infected (1.5%). These ratios are based on the actual fully vaccinated rate and Covid-19 cases (49 million) divided by the total population of the US (3,295 million). The right side of the process flow diagram is responsible for categorizing visitors' final status using the decision block and disposal block for analytical purposes. The following table describes how each block works to simulate the surface (fomite) transmission.

Table 2. Top-level Elements

Process Block	Function	Descriptions
Visitor Arrivals	Create entity (Visitors)	Interval=EXPO(45) Minutes
Decide Status	Decide Health Status 3 ways by chance	38.5% (a), 60% (b), 1.5% (c)
(a) Assign- Healthy but unvaccinated	Assign Attribute to the entity	Attribute- Health Status=0
(b) Assign- Healthy but vaccinated	Assign Attribute to the entity	Attribute- Health Status=1
(c) Assign- Infected	Assign Attribute to the entity	Attribute- Health Status=2
Record_1,2,3	Count visitors in each status	Initial Value=0
Get Infected	Decide Health Status by 2-way condition	If Health Status=2, go to the infected disposal. Else, go to the healthy disposal.
Re_Infected, Re_Healthy	Count infected and healthy visitors	Initial Value=0

Secondly, when visitors enter the fitness centers. They walk around and randomly decide whether to use the fitness equipment to work out. We assume there is a 50% chance for visitors to decide to use that equipment. If they do, they would have interaction with the equipment. We assume those infected visitors would leave viruses on the surfaces. We use the equipment sub-model (See Figure 4) from equipment 1 to 5 to demonstrate this concept. Figure 4 shows the sub-model of equipment 1. The rules apply to the rest of the 4.

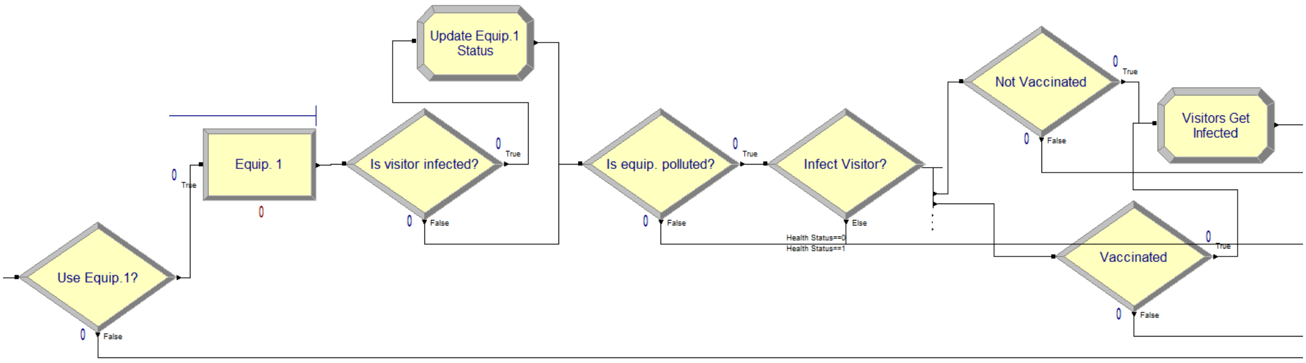

Figure 4. Equipment Sub-model Elements

To simulate surface transmission, each fitness equipment has a global variable, Equip. Status, indicating if it is contaminated by the virus. The condition for the equipment to get contaminated is through contact with infected visitors. If the equipment was contaminated, the variable of Equip. The Status would become 1 and the equipment would have the probability to infect the next healthy visitors who have contact with it. On the contrary, 0 means the equipment is clean and the healthy visitors won't get infected through contact with the fitness equipment. The table 3 shows the mechanism behind the sub-model of Equipment.

Table 3. Sub-model Elements

Process Block	Function	Descriptions
Use Equip.1?	Decide whether to interact with Equip. 1	50% choose to use, and 50% choose to skip to Equip. 2 submodel
Equip.1	Work-out Process for Equip. 1	EXPO (10) Minutes for the service time
Is Visitor Infected?	Decide by 2-way condition	If visitors' health status=2, the Boolean value would be True to contaminate the equipment, else would be False and skip to Equip. 2 submodel
Update Equip. 1 Status	Assign Contaminated Status to Equip. 1 Status	Assign Equip. 1 Status=1 (Contaminated)
Is equip. polluted?	Decide by 2-way condition	If Equip. 1 Status=1, the Boolean Value would be true, else would be False and skip to Equip. 2 submodel
Infect Visitor?	Decide by 3-way condition	If visitors' health status=0, lead to the decision blocks of unvaccinated, 1 for Vaccinated, and 2 would go to Equip. 2 submodel
Not vaccinated	Decide if healthy but unvaccinated visitors get infected	Infection Rate=50% to be true, False would skip to Equip. 2 submodel
Vaccinated	Decide if healthy and vaccinated visitors get infected	Infection Rate=5% to be true, False would skip to Equip. 2 submodel
Visitors Get Infected	Assign Infected Status to visitors	Set Health Status=2

Furthermore, we introduce 2 different scenarios to the simulation models, including no preventive measure, and regular disinfection. The first one means the fitness center doesn't take any action to prevent the virus infection. In the second scenario, the staff will clean the 5 fitness equipment every few hours. Once the fitness center conducts regular disinfection, the status of all the fitness equipment will be reset to 0, which is clean. It's worth noting that regular disinfection is an expensive policy. It requires extra staff and time to clean all the equipment. Therefore, we also attempt to test the infection ratios under various disinfection frequencies such as every 2 hours, 4 hours, 6 hours, or more. These settings help us to find the balance between the effects and costs of regular disinfection. The following Arena Block (Figure 5) shows how we implement regular disinfection.

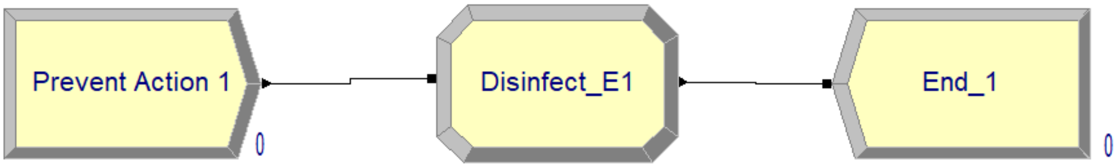

Figure 5. Regular Disinfection Flow

The disinfection event requires a create block generating entity 2, named as a fitness center, at a constant rate to trigger the Assign block, Disinfect_E1, to reset the global variable, Equip.1 Status into 0 every few hours.

Table 4. Regular Disinfection Elements

Process Block	Function	Descriptions
Prevent Action 1	Create	Constant Arrival, Every 2, 4,8 ,12 and 24 hours, 1 entity per arrival
Disinfect_E1	Assign	Reset global variable, Equip.1 Status=0
End_1	Disposal	Count the number of disinfection event

To summarize, by applying the above framework of 1 top-level and 5 submodels, we can simulate the surface transmission of viruses. We create Visitors' arrivals with Poisson Arrivals and assume there are 38.5% healthy but unvaccinated, 60% healthy and vaccinated, 1.5% infected visitors. They randomly select the fitness equipment from 1 to 5 in the center to interact. If infected visitors select and interact with the equipment, the equipment would get contaminated. The contaminated equipment has a probability of infecting other healthy visitors. We assume the infection rate is 50% for healthy visitors, but only 5% for vaccinated visitors.

Besides, we introduce the regular disinfection event to check its performance. Once the disinfection event occurs by the fitness center, all the equipment in the center would become clean. We test the arrival rate of 2, 4, 8, 12, and 24 hours to check the infection rate and evaluate the performance of regular disinfection in reducing infection.

5. Main Findings

In the simulation of surface transmission, we design the following scenarios to analyze the final infection rate. In this model, the virtual fitness center operates 24 hours a day and the experiment lasts for 30 days. The arrival rate of visitors has a time interval of exponential distribution with a mean of 45 minutes and each arrival has 1 entity. The service time of each piece of fitness equipment is an exponential distribution with a mean of 10 minutes. The simulation will run 30 times and we evaluate the results based on its average performance.

Table 5. Test Scenarios

Scenario	Vaccination Rate	Disinfect / 2 hours	Disinfect / 4 hours	Disinfect / 8 hours	Disinfect / 12 hours	Disinfect / 24 hours
A	60%					
B	98.5%					
C	60%	Yes				
D	60%		Yes			
E	60%			Yes		
F	60%				Yes	
G	60%					Yes

Scenario A represents the fitness center takes no action to prevent surface transmission. Scenario B indicates that the fitness center doesn't take any preventive measures, but every healthy visitor is fully vaccinated. Then scenarios C to G compare the infection rates under assumptions that the fitness center adopts different frequencies of disinfection. For example, in scenarios C, we assume the fitness center disinfects the place every 4 hours and Scenario G implements disinfection every 24 hours. After completing the simulation process, we obtain the following results in table 6:

Table 6. Simulation Outputs

Scenario	Total Visitors	Infected Visitors (beginning)	Infected Visitors (end)	Newly Infected	Newly Infected ratio
A	953.033	14.7	337.03	322.33	33.82%
B	958.1	13.33	112.93	99.6	10.40%
C	956.3	13.53	17.63	4.1	0.43%
D	960	14.27	24.37	10.1	1.05%
E	954.4	13.43	34.53	20.1	2.21%
F	953.03	14.1	47.3	33.2	3.48%
G	965.237	13.83	82.67	68.84	7.13%

The results show the regular disinfection is very helpful in reducing surface transmission. To be specific, If we compare A and C, the regular disinfection could reduce the newly infected ratio from 33.82% to 0.42% by cleaning every 2 hours. It demonstrates the importance of regular disinfection for public spaces. If the fitness center doesn’t want to do it that frequently due to the cost issues, they should disinfect at least once every 24 hours, which still reduces the Newly infected ratio from 33.82% to 7.13%.

Furthermore, vaccination is not sufficient to stop the spreading of the virus. Even though all the healthy visitors get vaccinated and reduce the infection probability from 50% to 5%, scenario B still shows another 10.4% of visitors might be infected.

6. Conclusions

Based on the experiments, the results showed that vaccination cannot sufficiently stop the spreading of the virus and regular disinfection could significantly reduce the newly infected ratio. However, our study has limitations. For example, although close contacts may occur among visitors, such as before and after visiting the center, this was not explicitly modeled. Our experiment also didn't consider the Covid-19 incubation period. The unvaccinated visitors or the healthy visitors could be in the incubation period without knowing they were infected. These limitations were assumed to be fixed rather than drawn from distributions, which may cause an underestimation of the uncertainty of pandemic trajectories but would not have affected the mean results. These findings suggest that the fitness center should conduct implement disinfection at least once every 24 hours and keep everyone at a distance. Regular disinfection significantly helps to reduce the risk of surface (fomite) transmission.

7. References

1. Centers for Disease Control and Prevention. *Science Brief: SARS-CoV-2 and Surface (Fomite) Transmission for Indoor Community Environments*. Centers for Disease Control and Prevention. Retrieved December 7, 2021, from https://www.cdc.gov/coronavirus/2019-ncov/more/science-and-research/surface-transmission.html
2. Arduin, H., Domenech de Cellès, M., Guillemot, D., Watier, L., & Opatowski, L. (2017, June 2). *An agent-based model simulation of influenza interactions at the host level: Insight into the influenza-related burden of pneumococcal infections*. BMC infectious diseases. Retrieved December 7, 2021, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5455134/.
3. Centers for Disease Control and Prevention. (2018, August 27). *How flu spreads*. Centers for Disease Control and Prevention. Retrieved December 7, 2021, from https://www.cdc.gov/flu/about/disease/spread.htm#:~:text=People%20with%20flu%20can%20spread,be%20inhaled%20into%20the%20lungs.
4. ED;, K. (2006, January). *Influenza pandemics of the 20th Century*. Emerging infectious diseases. Retrieved December 7, 2021, from https://pubmed.ncbi.nlm.nih.gov/16494710/
5. *Seir and SEIRS models*¶. SEIR and SEIRS models - HIV Model documentation. (n.d.). Retrieved December 7, 2021, from https://docs.idmod.org/projects/emod-hiv/en/latest/model-seir.html.