Methods/Results

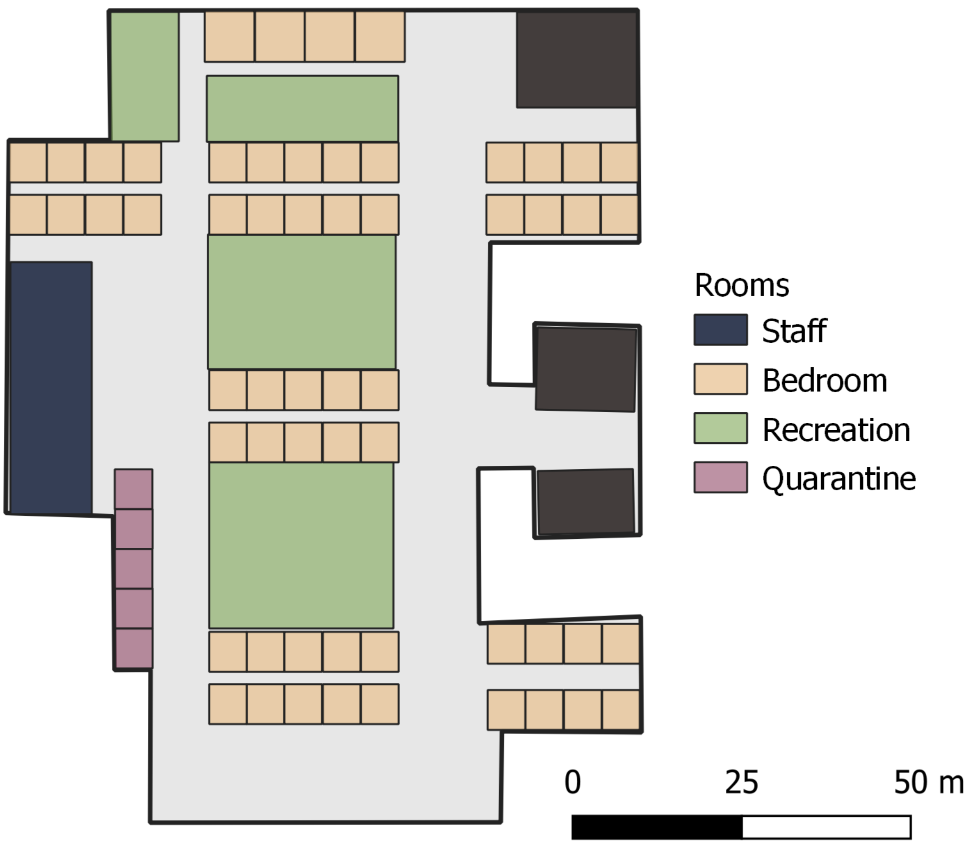
Methods

Population

We present a spatial explicit stochastic agent based model that recreates the day to day dynamics in a typical nursery home during the COVID pandemic in the United States. We use an hourly time step resolution and we ran the model for 150 days.

Population structure

We used the floor plans and satellite imagery to recreate the spatial structure of a typical nursery home in the US (figure 1). The nursery home consist on 58 bedrooms designated for the residents, recreation areas (such as dining room, and activities rooms), and rooms for staff use. In the initial conditions there are 3 residents per room (total 174) and 170 staff divided into 3 different turns. The decision on the population distribution was based on information obtained from an interview with a nursery home in California.



Population dynamics

In our simulation, an agent can interact with other agents based on its location. Given the current guidelines of recommendations for long term care facilities, there are no visitations and the residents spend most of the day in their rooms, so they can only interact with their roommates and the staff. In our model each resident will have at least one interaction with the staff per day which is based on different contact rates depending on the staff type (CN, RN, LPN), The staff will have different contact rates that were parametrized according on the average number of resident contacts in a normal day (REFERENCE: Table shared via email??). The contact rates are presented in table from supplementary materials.

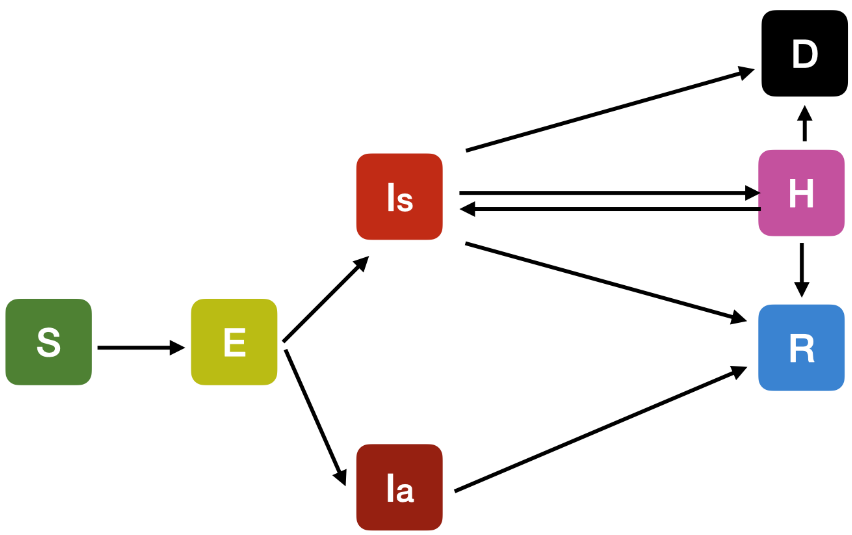
The staff agents are assigned to one of 3 different work schedules (morning, afternoon or night) and they spend 8 hours inside the nursery home and the rest of the time outside in the community. We only follow the agents inside the nursery home and when the agents are outside we assume that they all have the same probability of contacting other people.

Disease dynamics:

The transmission between agents inside the facility will depend on two parts, which are the probability that a person will shed the virus and the probability that another person will get the virus. We decided on model the transmission this way to represent scenarios where the infected and susceptible could have different combination of interventions (i.e. only infected received the intervention, only susceptible received the intervention, both received the intervention, etc..). The parametrization of the transmission parameters was based on observed outbreaks in nursery homes in California.

The introduction from the community to the facility depends on a parameter *Introduction_p* that represents how likely is that a staff agent will be infected in the community.

All the agents start as susceptible and after 1 day there is a resident introduced with the disease. Then we follow up for 150 days or until the disease has been absent for more than 14 simulation days. Once the transmission between a infectious agent to a susceptible agent has been successful, the susceptible agent becomes exposed and based on a distribution for the latent period λ, the agent becomes infectious after λ number of days, which can be either symptomatic and asymptomatic. The agent can infect other agents only when its in the Infectious state, then they remain infectious during 15 days and they transition to recovered. The agents can transition to infectious to hospitalized at any moment based on the hospitalization rate. When the agents has been recovered they acquire infection immunity, which lasts for 120 days.



Transmission parameters:

Name	Value	Reference
Latent period (λ)	$Lognormal(7,3)$	(He et al. 2020)[b,c]
Shedding probability	0.5	[a]
Infection probability	0.5	[a]
Introduction probability	0.01	[a]
Asymptomatic probability	0.25	[a]
Infection duration	15 *days*	
Hospitalization rate	0.11	

[a]Explored for sensitivity analysis and scenario modeling, [b]truncated distribution between a boundary of reasonable values, [c]fitted to a distribution

Interventions

We explore 3 different COVID-19 control strategies and the combination of them. Each of the interventions have an impact in the transmission of the disease, interventions such as the use of PPE and vaccination reduces the probability of transmission affecting directly the *Shedding* and *Infection probability*, while the isolation affects the transmission indirectly stopping the agent to interact with other agents. The equation 1 shows the effect of *PPE effect* and *Vaccine effect* on the transmission probability, where $odds_\omega$ represent the global transmission probability for all agents, OR_γ represent the odds ratio for the *PPE effect*, and $OR\pi$ is the *Vaccine effect*. This probability is computed for all agents at each step so we can have different probabilities of transmission based on the interventions each individual received.

$$p_T = \frac{e^{\ln(odds_\omega)+\ln(OR_\pi)+\ln(OR_\upsilon)}}{1 + e^{\ln(odds_\omega)+\ln(OR_\pi)+\ln(OR_\upsilon)}}$$

For the implementation of the vaccination, we specified by the proportion of residents and staff vaccinated, and a fixed interval between the first and second dose of 21 days. After the first dose, the agents will only obtain a 60% of the total immunity protection assumed to be conferred by the vaccine, then on the second dose the agents will have 100% of the assumed effect. Then the vaccination immunity will have a decay of 120 days and the individual will no longer have the vaccination immunity protective effect.

Since there is still some uncertainty in the effect of the use of PPE and the vaccine for older population, we started with values that are within the range of reported values and then varied these values for the sensitivity analysis and scenario modeling.

Testing and isolation

Our model represents the testing of the population with 2 different approaches:

- Passive, individuals are tested once that they present symptoms, this approach is focused on the early detection of symptomatic individuals.
- Active, a proportion of individuals are tested with a given frequency. In baseline scenario, 1 resident per room and all the staff are tested weekly. If 1 of the residents in a room is detected positive, the rest of the residents in that room are also tested.

Once a individual has been detected positive is isolated. There are special isolation rooms for the residents and in the case of the staff they are sent home. Once the individual is tested negative it return to the facility.

Interventions parameters:

Name	Value	Reference
Test detection probability	85%	[a]
Proportion of Staff tested	90%	[a]
Proportion of Residents tested	33.3	[a]
Frequency of testing	Weekly	[a]
PPE Effect (OR_π)	0.34089	(Chu et al. 2020)[a]
Vaccine effect (OR_υ)	0.0493	(Pfizer-BioNTech 2020)[a]
Vaccine immunity duration	120 *days*	[a]

[a]Explored for sensitivity analysis and scenario modeling, [b]truncated distribution between a boundary of reasonable values, [c]fitted to a distribution

Sensitivity analysis

We performed sensitivity analysis on selected parameters to show the influence of these parameters on the outcomes.

To effect of the vaccine on reducing the transmission we parametrized the model according to the current vaccine effect reported by the trials from the Moderna and Pfizer vaccine (Baden et al. 2020; Polack et al. 2020). Since there is still some uncertainty about the effect of the vaccine in population >65 years, we defined 3 scenarios that explore the possible outcomes under 3 different assumptions:

- Equal effect: The vaccine has the same effect both populations (>65 years and >65 years).
- Pfizer: The vaccine is less effective on populations >65 years parametrized according to the reported by (Baden et al. 2020).
- Moderna: The vaccine is less effective on populations >65 years parametrized according to the reported by (Polack et al. 2020).

The parameters used to explore the vaccine effect used are the following:

Scenario	$OR_{V,S}$	$OR_{V,R}$	V_S	V_R
Equal effect	0.0493	0.0493	80%	20%
Pfizer	0.0434	0.0619	80%	20%
Moderna	0.0441	0.1357	80%	20%

Scenario modeling

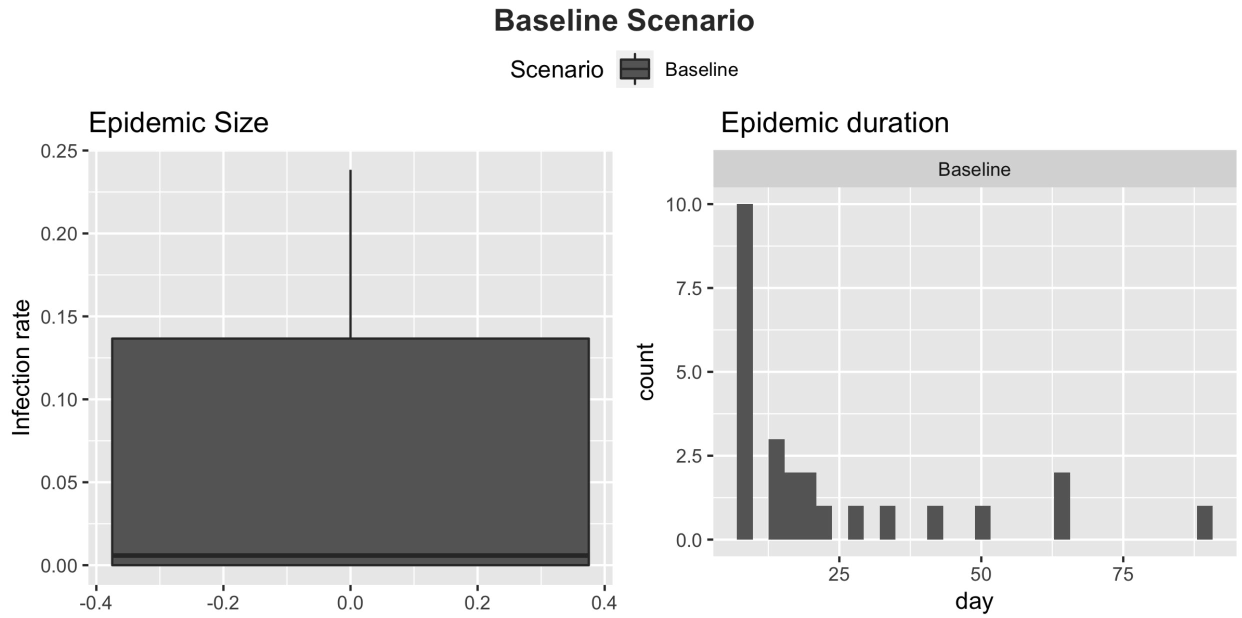
To illustrate the applications of our model we wanted to answer the question "How should the resources should be distributed under two different levels of community transmission?". We defined as a low community transmission where the probability of introduction is 1% and high community transmission where the probability of introduction is 5%. Then we used the worst case scenario for the effect of the vaccine on the two age groups and looked at the disease outcomes including infection rate and time to duration of the outbreak.

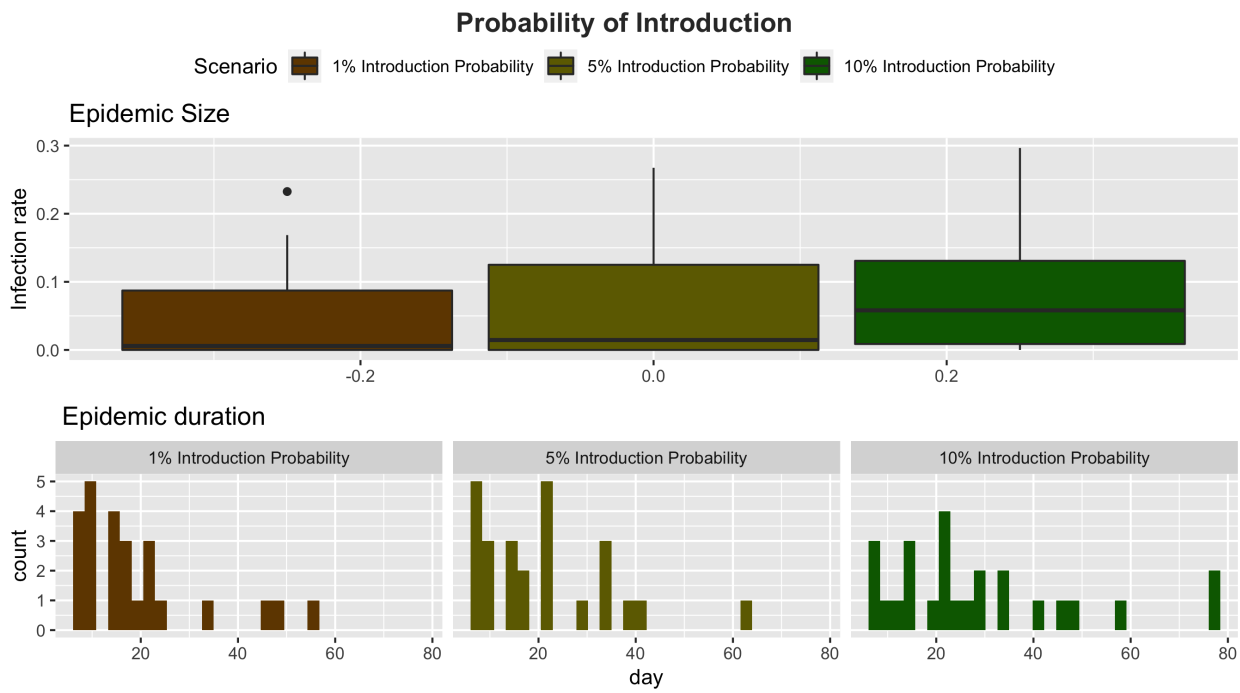
Scenario	$OR_{V,S}$	$OR_{V,R}$	V_S	V_R	Probability of introduction
S00	0.0441	0.1357	50%	50%	1%
S01	0.0441	0.1357	80%	20%	1%
S02	0.0441	0.1357	20%	80%	1%
S03	0.0441	0.1357	50%	50%	5%
S04	0.0441	0.1357	80%	20%	5%
S05	0.0441	0.1357	20%	80%	5%

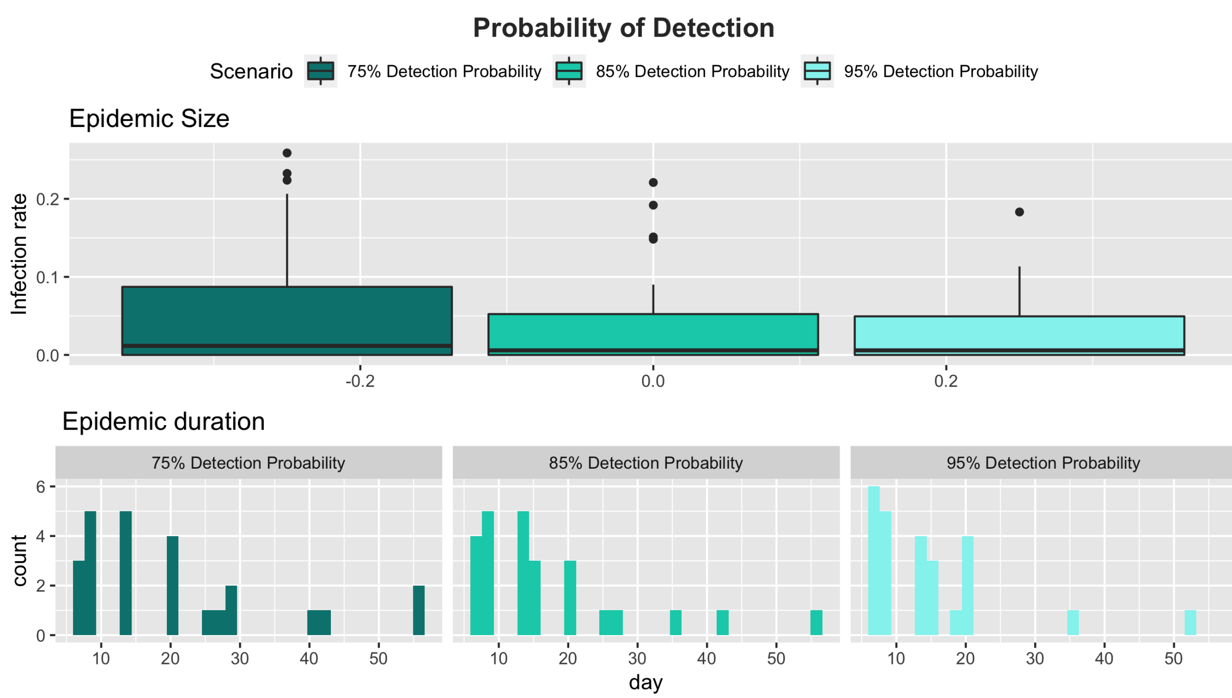
Results

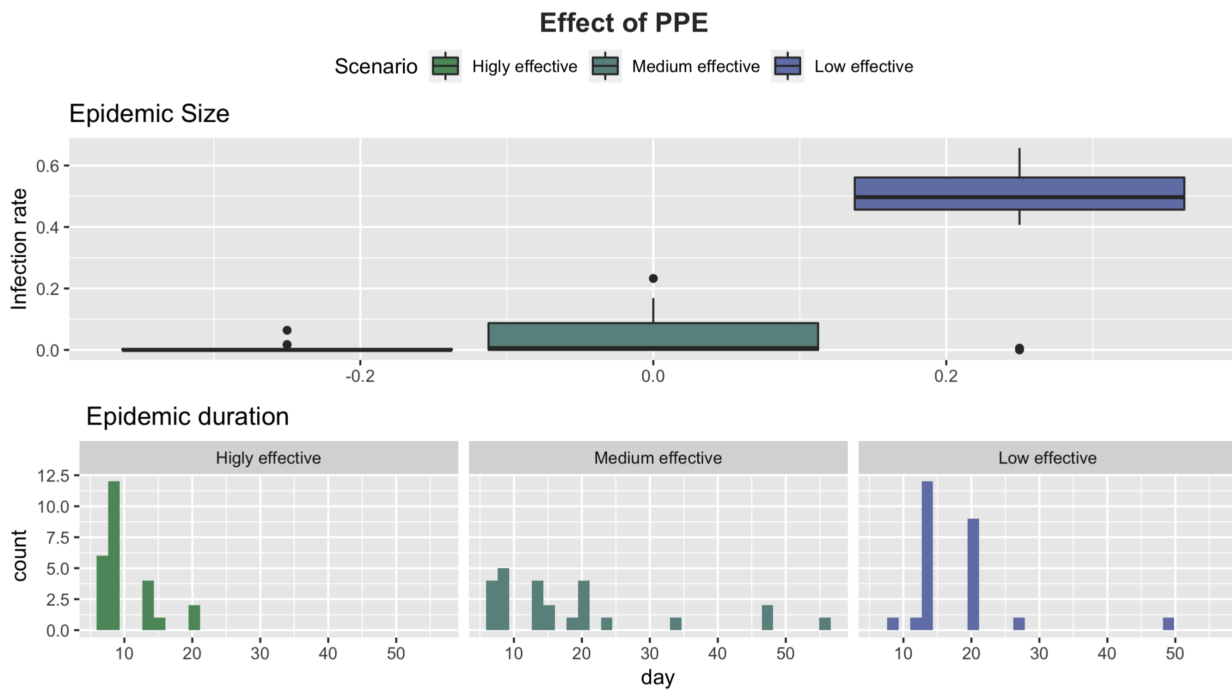
Sensitivty analisis

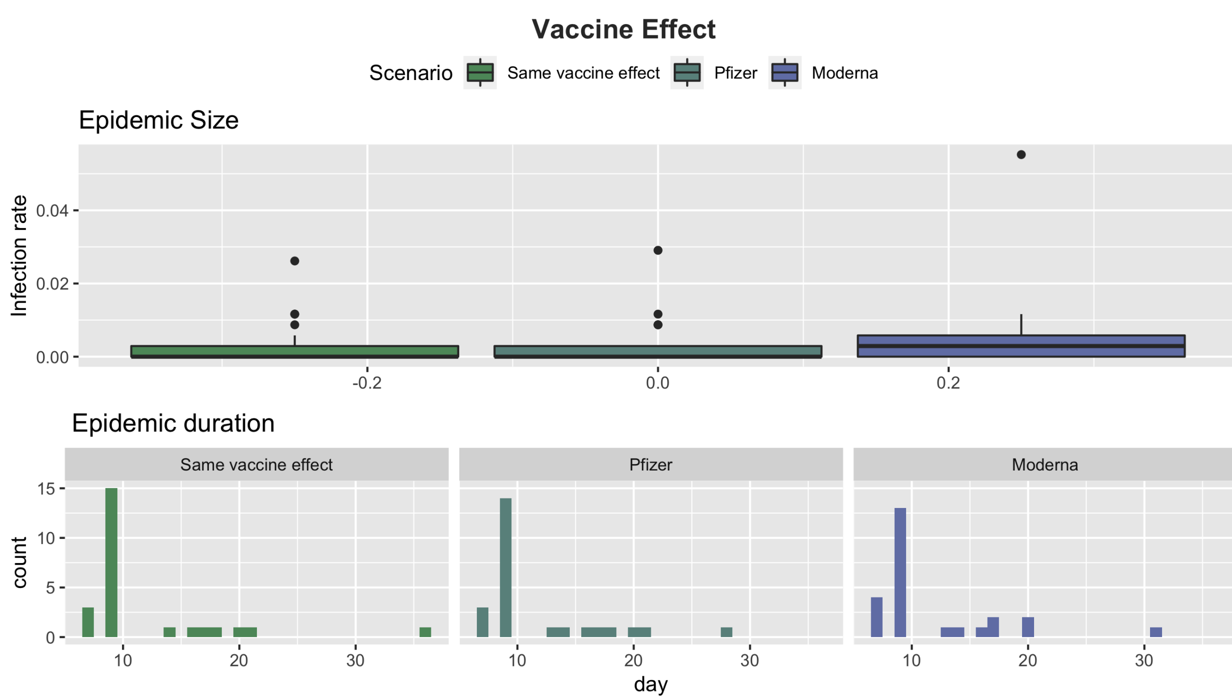
For the sensitivity analysis we parted from a baseline scenario following the current interventions implemented in a typical nursery home. Testing is performed once a week to all the staff and one resident per room. Once that the resident is detected positive is sent to a isolation room, and in the case that one of the staff members test positive, it will be send home. Both the staff and residents are required to use PPE. Then we varied some of the model parameters to explore the influence on the outbreak size and duration.




Probability of Introduction
Scenario
1% Introduction Probability
5% Introduction Probability
10% Introduction Probability
Epidemic Size
Infection rate
0.3
0.2
0.1
0.0
-0.2
0.0
0.2
Epidemic duration
1% Introduction Probability
5% Introduction Probability
10% Introduction Probability
count
5
4
3
2
1
0
20
40
60
80
day


Probability of Detection
Scenario
75% Detection Probability
85% Detection Probability
95% Detection Probability
Epidemic Size
Infection rate
0.2
0.1
0.0
-0.2
0.0
0.2
Epidemic duration
75% Detection Probability
85% Detection Probability
95% Detection Probability
count
6
4
2
0
10
20
30
40
50
day

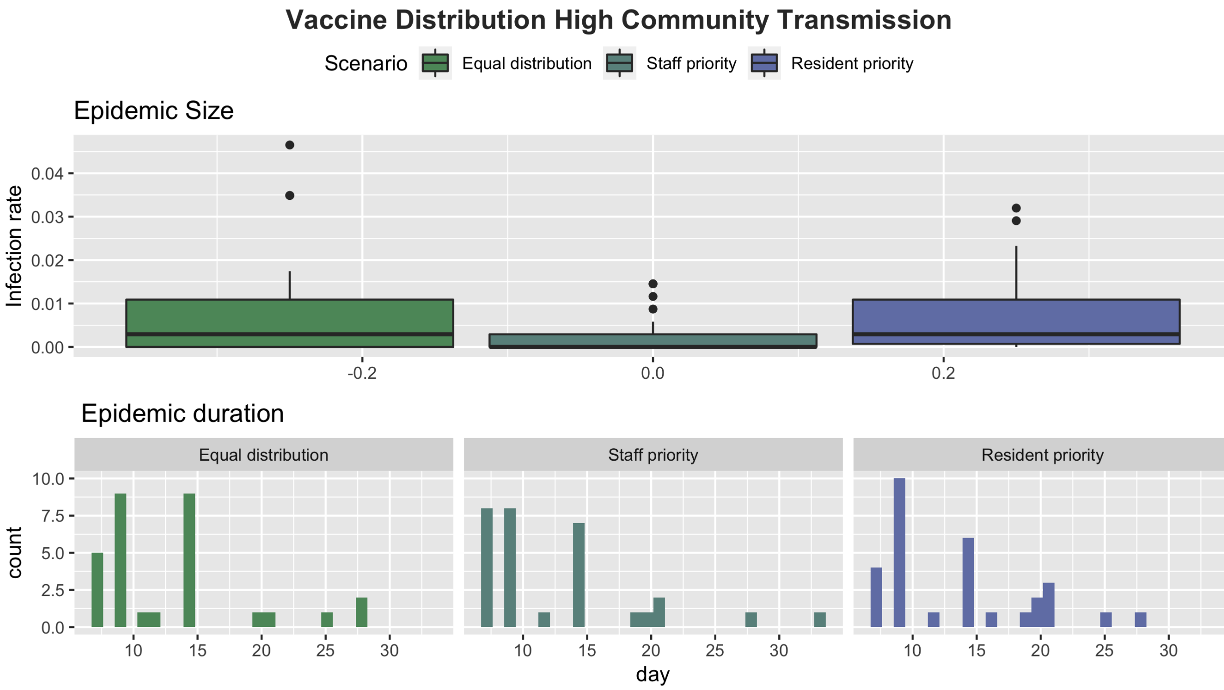




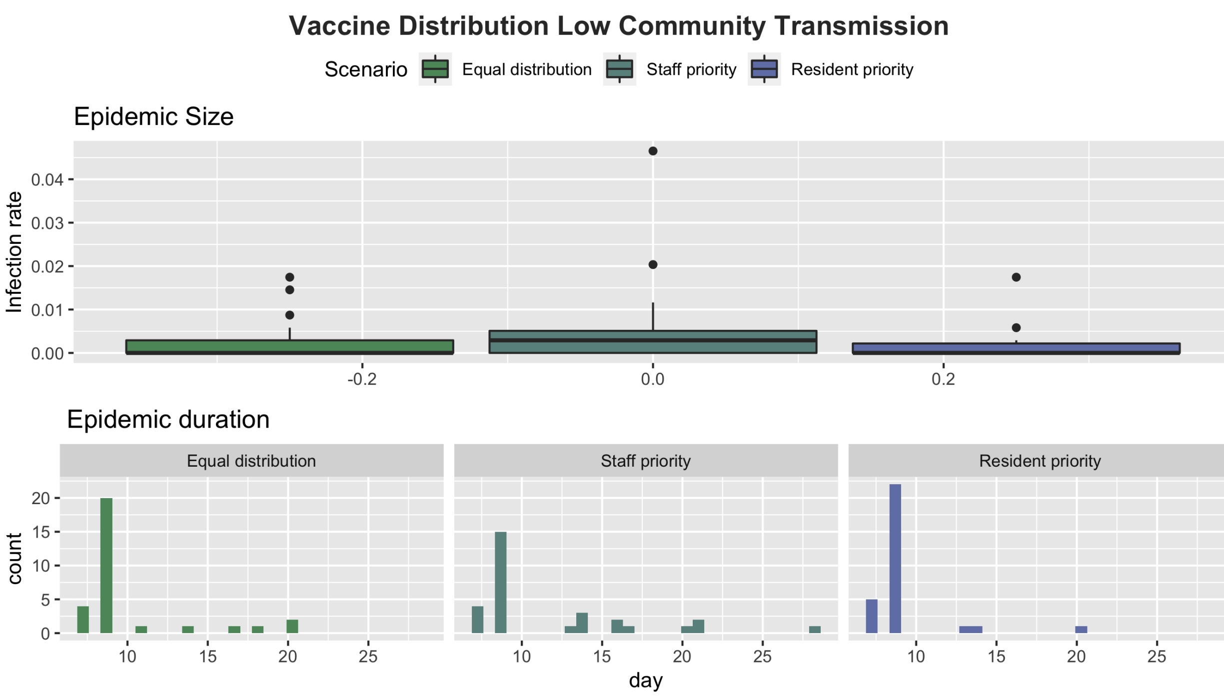
Scenario modeling

To compare the different scenarios we looked at the cumulative infection rate and the outbreak duration. As expected, the disease impact was lower in scenarios where the probability of introduction was lower. Looking only at the scenarios with a low probability of introduction (I00, I01, I02), we notice that the scenario where the resident vaccination is prioritized (02) has the smaller outbreaks. But when we look only at the scenarios with high probability of introduction, the scenario where the staff vaccination is prioritized gives the smaller outbreaks.

With 5% probability of introduction:



with 1% probability of introduction:



Scenario	Mean Infection Rate	Mean Outbreak duration
00	0.004	10.26
01	0.007	11.90
02	0.002	9.33
03	0.015	12.90

Scenario	Mean Infection Rate	Mean Outbreak duration
04	0.009	12.66
05	0.013	13.50

References

Baden, Lindsey R., Hana M. El Sahly, Brandon Essink, Karen Kotloff, Sharon Frey, Rick Novak, David Diemert, et al. 2020. "Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine." *New England Journal of Medicine*, December, NEJMoa2035389. https://doi.org/10.1056/NEJMoa2035389.

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