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# Modeling the Spread of COVID-19 among People in ICE Detention with Book-in, Transfer, and Book-out Dynamics

## Technical Appendix

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## Compartmental epidemiology model

Our model is an adaptation of the Susceptible, Exposed, Infectious, Removed (SEIR) model in the paper by Lofgren et al.<sup>1</sup> We use their “jail, low-risk adult” component to model each ICE detention facility, because the available evidence suggests that a clear majority of people detained by ICE are at or under 45 years of age.<sup>2</sup> However, we have adjusted some of the Lofgren et al. probability parameters, and have changed our transmission rate parameter  $\beta$  to be consistent with a  $R_0$  reproduction number of 7 as in the pessimistic scenario of the Irvine et al. paper.<sup>3</sup> As a point of reference, the highest estimate of  $R_0$  for COVID-19 that we are aware of is a value of 14.8 found in a study of the outbreak on the Diamond Princess cruise ship.<sup>4</sup> We also used the Recidiviz COVID-19 model as a reference for how to implement a discrete-time SEIR model.<sup>5</sup>

We integrate the Lofgren et al. core component into a metapopulation model of hundreds of ICE detention facilities, in which ICE books people into detention facilities, transfers people between facilities, and books people out into the general population or deports them. In order to model transfers of people between facilities, we choose a discrete time, stochastic agent-based model with mass action. The daily transitions of people between disease compartments as well as ICE detention facilities are modeled as a Markov chain. We use a Monte Carlo simulation to explore the distribution of disease outcomes and associated transfers.

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<sup>1</sup> Eric Lofgren, Kristian Lum, Aaron Horowitz, Brooke Madubuonwu, Kellen Myers, and Nina H. Fefferman, “The Epidemiological Implications of Incarceration Dynamics in Jails for Community, Corrections Officer, and Incarcerated Population Risks from COVID-19,” <https://www.medrxiv.org/content/10.1101/2020.04.08.20058842v2>.

<sup>2</sup> Freedom for Immigrants posted a histogram of 5,823 age observations that they collected from people detained by ICE, from which we ascertained that that roughly 80 percent of people in their sample were at or under the age of 45. See Freedom for Immigrants, “Detention by the Numbers,” accessed May 29, 2020, <https://www.freedomforimmigrants.org/detention-statistics>. The Transactional Records Access Clearinghouse found a median age of 30 among people deported by ICE in FY 2012 and FY 2013. See Transactional Records Access Clearinghouse, “ICE Deportations: Gender, Age, and Country of Citizenship,” April 9, 2014, <https://trac.syr.edu/immigration/reports/350/>.

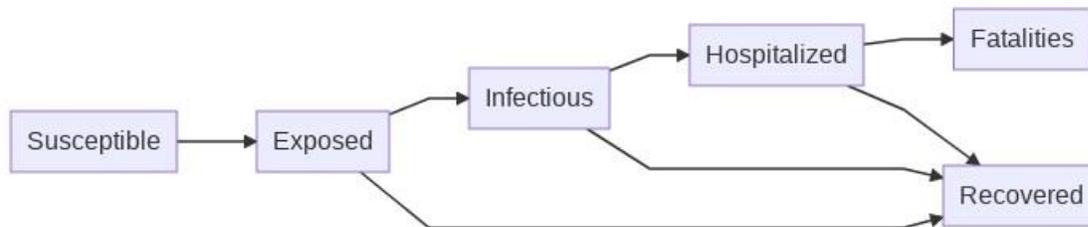
<sup>3</sup> Our transmission rate parameter  $\beta$  is set to be consistent with a  $R_0$  of 7 in a closed detention facility setting in which the population is static, which is what the Irvine et al. paper assumes. However, in our simulation the detention center populations are not static and ICE books people in, transfers people to other facilities, and books people out, so the  $R_0$  will not be the same. See Michael Irvine, Daniel Coombs, Julianne Skarha, Brandon del Pozo, Josiah Rich, Faye Taxman, and Traci C. Green, “Modeling COVID-19 and Its Impacts on U.S. Immigration and Customs Enforcement (ICE) Detention Facilities, 2020,” *Journal of Urban Health* (2020), <https://doi.org/10.1007/s11524-020-00441-x>.

<sup>4</sup> J Rocklöv, HSjödín, and A Wilder-Smith, “COVID-19 outbreak on the Diamond Princess cruise ship: estimating the epidemic potential and effectiveness of public health countermeasures,” *Journal of Travel Medicine* 27, no. 3 (April 2020), 1-7, <https://academic.oup.com/jtm/article/27/3/taaa030/5766334>.

<sup>5</sup> Recidiviz SEIR model code in the Recidiviz COVID-19 Dashboard GitHub repository, accessed May 22, 2020, <https://github.com/Recidiviz/covid19-dashboard/blob/master/src/infection-model/seir.tsx>.

## Overview of compartmental model

In our model there are six compartments: **Susceptible**, **Exposed**, **Infectious**, **Hospitalized**, **Fatalities**, and **Recovered**.



Individuals start in the **Susceptible** compartment. Some fraction of them will come into contact with contagious individuals and transition into the **Exposed**, asymptomatic compartment.

In the **Exposed** compartment, we assume that people are partially contagious. Some of these people transition into the **Infectious**, symptomatic compartment. The rest of the people in the **Exposed** compartment will never develop symptoms and instead transition into the **Recovered** compartment.

In the **Infectious** compartment, we assume that people are fully contagious. Some people will transition into the **Hospitalized** compartment, whereas the rest will transition into the **Recovered** compartment.

In the **Hospitalized** compartment, people are assumed to no longer be physically able to contact and infect other people in the detention facility. Some people will die from COVID-19 and transition into the **Fatalities** compartment. The rest will transition into the **Recovered** compartment.

In the **Recovered** compartment, people are no longer contagious. People transition into **Recovered** from the **Exposed**, **Infectious**, and **Hospitalized** compartments, and once in **Recovered**, they do not leave.

In the **Fatalities** compartment, people are no longer contagious. People transition into **Fatalities** if they die of COVID-19 in the **Hospitalized** compartment.

## Overview of how people are booked-in, transferred, and booked-out by ICE in compartmental model

We model ICE's actions of booking-in, transferring, and booking-out people using ICE detention data obtained through the Freedom of Information Act (FOIA) via David Hausman at the Immigration Policy Lab. We combined this ICE detention data with ICE facility location data compiled by the Marshall Project.<sup>6</sup> Daily transition probabilities are calculated using FY2016 data, which is the most recent full fiscal year of data available. We likewise use FY 2016 data to calculate average facility populations that we seed the simulation with.

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<sup>6</sup> The Marshall Project, *Detained* GitHub repository, ICE detention locations file, accessed February 24, 2020, [https://github.com/themarshallproject/dhs\\_immigration\\_detention/blob/master/locations.csv](https://github.com/themarshallproject/dhs_immigration_detention/blob/master/locations.csv).

We have not yet attempted to model the COVID-19 dynamics in the general population, but instead set the fraction of Exposed and Susceptible people in the general population to be constant at probabilities  $p_{\text{exposed}}$  and  $1 - p_{\text{exposed}}$ , respectively. We initialize the simulation with everyone in ICE detention facilities being in the Susceptible compartment. In our simulation, COVID-19 will initially arrive inside facilities through ICE booking Exposed people in from the general population, and will additionally spread through ICE transferring Exposed and Infectious people between facilities.

Lastly, we scale the estimated book-in probabilities to provisionally calibrate our model, roughly matching ICE initial book-ins and Average Daily Population (ADP) during [March 2020](#).<sup>7</sup> This calibration causes the overall facility populations to drift downward throughout our simulation.

## Transition probabilities

### Probabilities of transitions between SEIR compartments

For a given ICE detention facility at time  $t$ , let the aggregate number of people in the Susceptible, Exposed, Infectious, Hospitalized, Recovered, and Fatalities compartments be given by  $S(t)$ ,  $E(t)$ ,  $I(t)$ ,  $H(t)$ ,  $R(t)$ , and  $F(t)$  respectively. The total number of people in the detention facility at  $t = 0$  is given by  $N = N(0)$ .

Let the SEIR compartment that an individual person is in at time  $t$  be given by a categorical random variable  $X_t \in \{\text{Susceptible}, \text{Exposed}, \text{Infectious}, \text{Hospitalized}, \text{Recovered}, \text{Fatalities}\}$ .

In what follows, individual and facility-level subscripts have been suppressed.

#### *Susceptible*

The probability of transitioning from Susceptible to Exposed for any given person in the Susceptible compartment is given by:

$$p(X_{t+1} = \text{Exposed} | X_t = \text{Susceptible}) = \beta * \frac{I(t) + p_{\text{transmission reduction}} * E(t)}{N}$$

#### *Exposed*

The probability of transitioning between Exposed and Infectious for any given person in the Exposed compartment is given by:

$$p(X_{t+1} = \text{Infectious} | X_t = \text{Exposed}) = \frac{1}{\text{days}_{\text{incubation}}}$$

The probability of transitioning between Exposed and Recovered for any given person in the Exposed compartment is given by:

$$p(X_{t+1} = \text{Recovered} | X_t = \text{Exposed}) = \frac{1}{\text{days}_{\text{asymptomatic}}}$$

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<sup>7</sup> U.S. Immigration and Customs Enforcement, “Detention Management,” Detention Statistics tab, accessed May 26, 2020, <https://www.ice.gov/detention-management#tab2>.

### *Infectious*

The probability of transitioning between Infectious and Hospitalized for any given person in the Infectious compartment is given by:

$$p(X_{t+1} = \text{Hospitalized} | X_t = \text{Infectious}) = \frac{p_{\text{hospital}}}{\text{days}_{\text{hospital lag}}}$$

The probability of transitioning between Infectious and Recovered for any given person in the Infectious compartment is given by:

$$p(X_{t+1} = \text{Recovered} | X_t = \text{Infectious}) = \frac{1 - p_{\text{hospital}}}{\text{days}_{\text{symptomatic}}}$$

### *Hospitalized*

The probability of transitioning between Hospitalized and Fatalities for any given person in the Hospitalized compartment is given by:

$$p(X_{t+1} = \text{Fatalities} | X_t = \text{Hospitalized}) = \frac{1 - p_{\text{survival}}}{\text{days}_{\text{hospital fatality}}}$$

The probability of transitioning between Hospitalized and Recovered for any given person in the Hospitalized compartment is given by:

$$p(X_{t+1} = \text{Recovered} | X_t = \text{Hospitalized}) = \frac{p_{\text{survival}}}{\text{days}_{\text{hospital}}}$$

### *Recovered*

Recovered is an absorbing state in this model.

### *Fatalities*

Fatalities is an absorbing state in this model.

### **Probabilities of transitions between facilities**

For each person, each daily simulation draw for SEIR compartment is accompanied by an independent draw for book-out or transfer from one ICE detention facility to another, according to the transfer probabilities calculated from FY2016 ICE data. Between time  $t$  and  $t + 1$  the transition of disease compartment is modeled as occurring simultaneously with the transfer from one facility to another.

We restrict transfers between time  $t$  and  $t + 1$  such that people who are in the Hospitalized or Fatalities compartments at time  $t$  have no chance of being transferred or booked-out at time  $t + 1$ .

## Parameter derivations

### Instantaneous probability calculations

If the cumulative probability of hospitalization conditional on being in the Infectious state is 0.0625, then the instantaneous probability of hospitalization is given by:

$$\frac{\frac{p_{\text{hospital}}}{\text{days}_{\text{hospital lag}}}}{\frac{p_{\text{hospital}}}{\text{days}_{\text{hospital lag}}} + \frac{1 - p_{\text{hospital}}}{\text{days}_{\text{symptomatic}}}} = 0.0625$$
$$\frac{p_{\text{hospital}}}{p_{\text{hospital}} + (1 - p_{\text{hospital}}) \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}}} = 0.0625$$
$$p_{\text{hospital}} = 0.0625 * (p_{\text{hospital}} (1 - \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}}) + \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}})$$
$$p_{\text{hospital}} (1 - 0.0625 (1 - \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}})) = 0.0625 \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}}$$
$$p_{\text{hospital}} = \frac{0.0625 \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}}}{(1 - 0.0625) + 0.0625 \frac{\text{days}_{\text{hospital lag}}}{\text{days}_{\text{symptomatic}}}}$$

We calculated other instantaneous probabilities from cumulative probabilities found in Lofgren et al. and transition rates using analogous formulas.

### Derivation of transmission rate parameter $\beta$

We adopted a value for the  $\beta$  transmission rate parameter that would be consistent with a  $R_0$  reproduction number of seven if ICE facilities were static and closed, even though in our actual model the facilities are dynamic and open.

$\beta$  is derived as follows:

$$\beta \times \text{average time infected} = R_0$$
$$\beta \times \left( \frac{\frac{p_{\text{transmission reduction}}}{1}}{\text{days}_{\text{incubation}} + \frac{1}{1}} + \frac{1}{\frac{p_{\text{hospital}}}{\text{days}_{\text{hospital lag}}} + \frac{1 - p_{\text{hospital}}}{\text{days}_{\text{symptomatic}}}} \right) = R_0$$

## Parameter Table

Parameter	Value
$\beta$	0.625
$p_{\text{transmission reduction}}$	0.5
$\text{days}_{\text{incubation}}$	5.1
$\text{days}_{\text{asymptomatic}}$	6.7
$\text{days}_{\text{symptomatic}}$	10
$\text{days}_{\text{hospital lag}}$	5.9
$\text{days}_{\text{hospital}}$	9
$\text{days}_{\text{hospital fatality}}$	4.2
$p_{\text{hospital}}$	0.0378
$P_{\text{survival}}$	0.9760
$p_{\text{exposed}}$	0.002