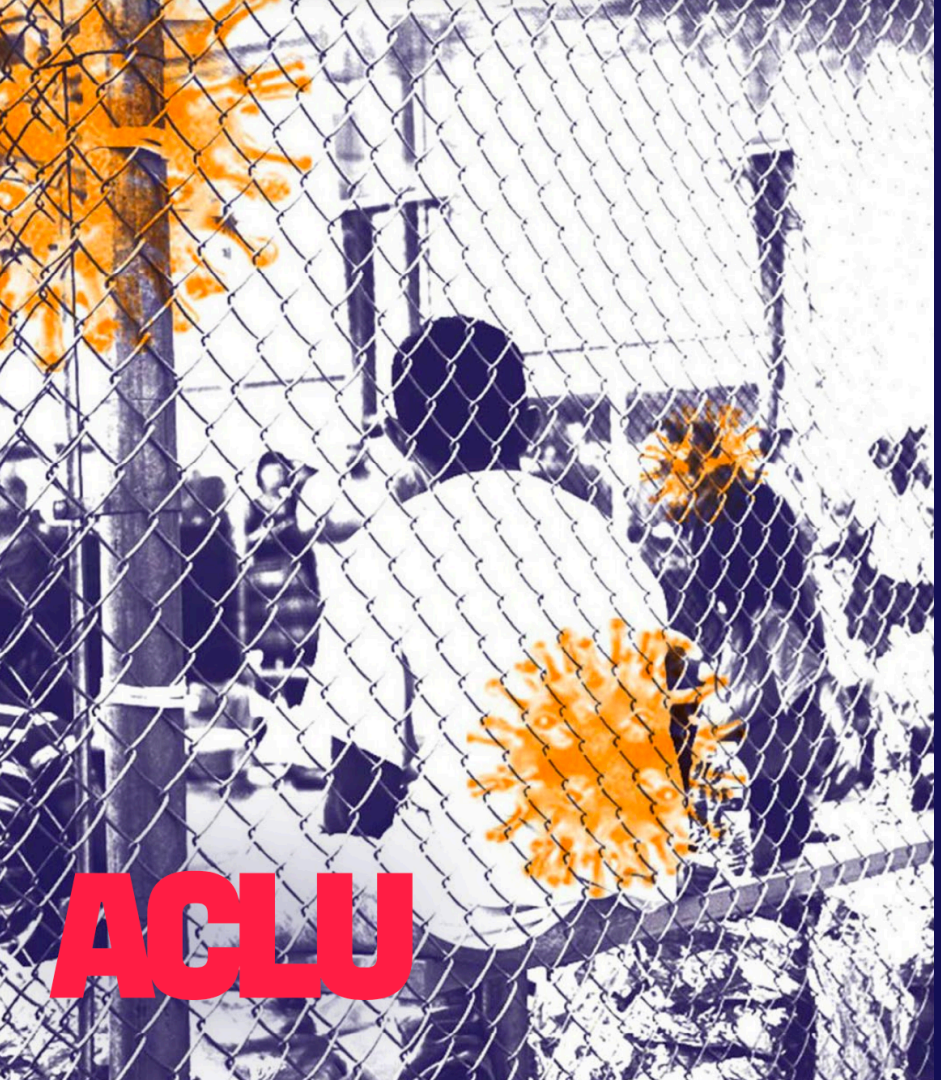

Modeling COVID-19 in jails

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Overview

- Why focus on jails?
- Modeling a single jail outbreak
- Challenges and lessons from modeling at scale
- Epidemiological models in advocacy & litigation

Background

10 of 10 largest COVID-19 hotspots are jails or prisons.

Search clusters

CASES CONNECTED TO	
Marion Correctional Institution — Marion, Ohio	
San Quentin State Prison — San Quentin, Calif.	2,435
Harris County jail — Houston, Texas	1,913
Pickaway Correctional Institution — Scioto Township, Ohio	1,794
Avenal State Prison — Avenal, Calif.	1,448
Trousdale Turner Correctional Center — Hartsville, Tenn.	1,382
North County jail — Castaic, Calif.	1,380
Columbia Correctional Institution — Lake City, Fla.	1,373
Ouachita River Unit prison — Malvern, Ark.	1,307
California Institution for Men — Chino, Calif.	1,184

7 prisoners with coronavirus died at San Quentin and hundreds more are dying in US jails and prisons

By Nicole Chavez, CNN

Updated 12:38 AM ET, Fri July 10, 2020

Pregnant And Scared, She Became The First Woman Federal Prisoner To Die Of COVID-19

Andrea Circle Bear told her grandmother she had pneumonia when prison officials took her to a nearby hospital. She was put on a ventilator the next day and had to give birth two months early.

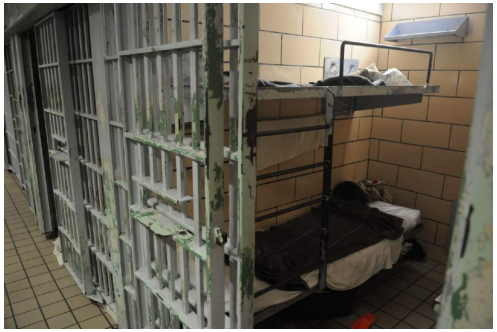
- **Patrick Jones, 49, has been identified as the first federal inmate to die from the novel coronavirus.**
- **Jones, who was 13 years into a 27-year sentence on non-violence drug charges, requested a sentence reduction in October 2019 but was denied in late February.**

Jail is one of the largest risk factors for COVID-19.

CORONAVIRUS

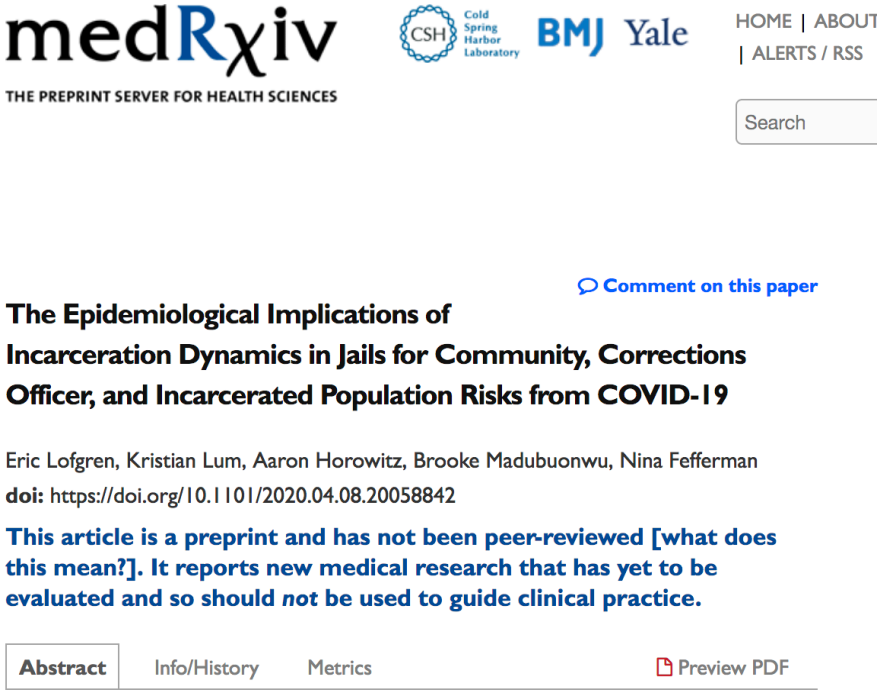
The Prison Was Built to Hold 1,500 Inmates. It Had Over 2,000 Coronavirus Cases.

Prison overcrowding has been quietly tolerated for decades. But the pandemic is forcing a reckoning.



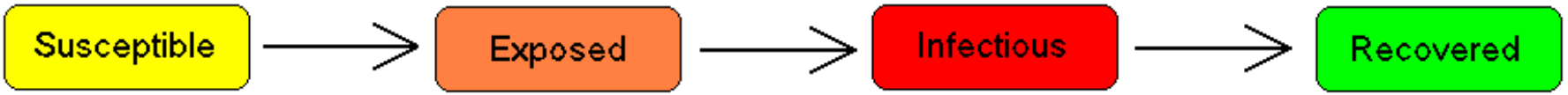
Above: Harris County jail, TX. *Photo credit: Caleb Bryant Miller, The Texas Tribune*
Left: Fayette County Prison, PA. *Photo credit: Evan Sanders, Trib Total Media.*

COVID-19 in jails



Modeling 1 outbreak

A simplified compartmental model in pictures



A simplified compartmental model in math

$$\frac{dS}{dt} = \Lambda - \mu S - \frac{\beta I S}{N}$$

$$\frac{dE}{dt} = \frac{\beta I S}{N} - (\mu + a)E$$

$$\frac{dI}{dt} = aE - (\gamma + \mu)I$$

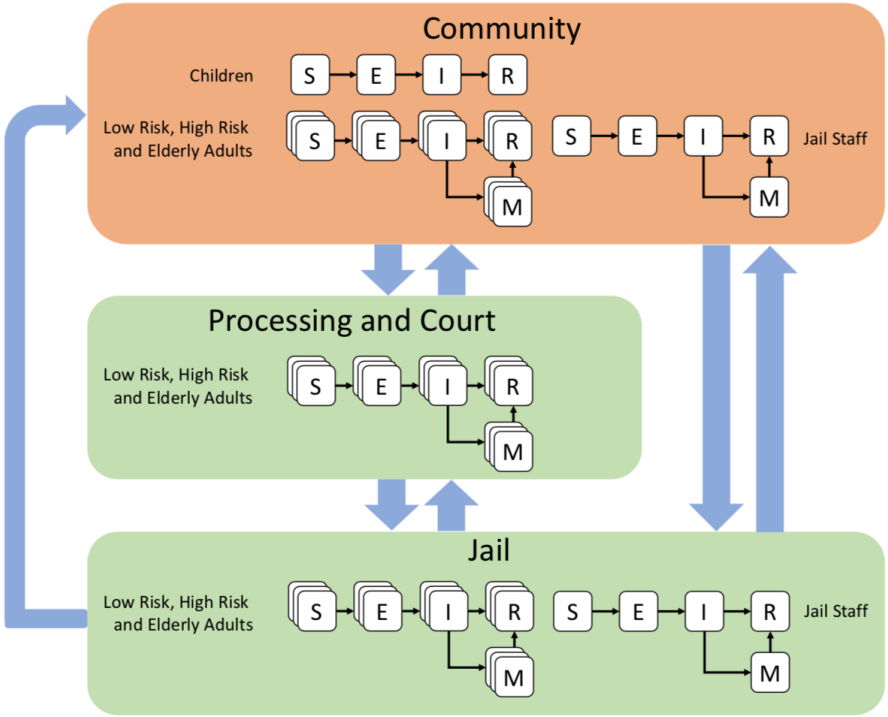
$$\frac{dR}{dt} = \gamma I - \mu R.$$

A simplified compartmental model in R

```
require(deSolve)

model <- function(t, beta, gamma,
delta){

  xstart <- c(S=10000,
              E=0,
              I=1,
              R=0)

  params <- c(b = beta,
              g = gamma,
              d = delta)

  times <- seq(0,t*24,by=1)
  }
```

```
mod <- function(time,state,parameters){

  with(as.list(c(start,params)),{
    dS <- -b*S*I
    dE <- b*S*I - d*E
    dI <- d*E - g*I
    dR <- g*I
    return(list(c(dS,dI,dR)))
})}

res <- lsoda(y=xstart,
             times=time,
             mod,
             parms=parameters)

res.df<-as.data.frame(res)
```

A complex compartmental model in pictures



A complex compartmental model in Math

$$\frac{dE_E^C}{dt} = \beta_{EK}^C S_E^C \left(I_K^C + \sigma E_K^C\right) + \beta_{EL}^C S_E^C \left(I_L^C + I_O^C + \sigma\left(E_L^C + E_O^C\right)\right) + \beta_{EE}^C S_E^C \left(I_E^C + \sigma E_E^C\right) + \beta_{EH}^C S_E^C \left(I_H^C + \sigma E_H^C\right) - (\gamma + \hat{\gamma}) E_E^C - \alpha_E E_E^C + \psi_C E_E^P + \rho E_E^J$$

$$\frac{dI_E^C}{dt} = \gamma E_E^C - \delta I_E^C - \omega_H I_E^C - \alpha_H I_E^C + \psi_C I_E^P + \rho I_E^J$$

$$\frac{dM_E^C}{dt} = \omega_H I_E^C - \delta_{Discharge}\nu_H M_E^C - \delta_{Death}(1-\nu_H) M_E^C$$

$$\frac{dR_E^C}{dt} = \delta I_E^C + \hat{\gamma} E_E^C + \delta_{Discharge}\nu_H M_E^C + \delta_{Death}(1-\nu_H) M_E^C - \alpha_H R_E^C + \psi_C R_E^P + \rho R_E^J$$

$$\frac{dS_H^C}{dt} = -\beta_{HK}^C S_H^C \left(I_K^C + \sigma E_K^C\right) - \beta_{HL}^C S_H^C \left(I_L^C + I_O^C + \sigma\left(E_L^C + E_O^C\right)\right) - \beta_{HE}^C S_H^C \left(I_E^C + \sigma E_E^C\right) - \beta_{HH}^C S_H^C \left(I_H^C + \sigma E_H^C\right) - \alpha_H S_H^C + \psi_C S_H^P + \rho S_H^J$$

$$\frac{dE_H^C}{dt} = \beta_{HK}^C S_H^C \left(I_K^C + \sigma E_K^C\right) + \beta_{HL}^C S_H^C \left(I_L^C + I_O^C + \sigma\left(E_L^C + E_O^C\right)\right) + \beta_{HE}^C S_H^C \left(I_E^C + \sigma E_E^C\right) + \beta_{HH}^C S_H^C \left(I_H^C + \sigma E_H^C\right) - (\gamma + \hat{\gamma}) E_H^C - \alpha_H E_H^C + \psi_C E_H^P + \rho E_H^J$$

$$\frac{dI_H^C}{dt} = \gamma E_H^C - \delta I_H^C - \omega_H I_H^C - \alpha_H I_H^C + \psi_C I_H^P + \rho I_H^J$$

$$\frac{dM_H^C}{dt} = \omega_H I_H^C - \delta_{Discharge}\nu_H M_H^C - \delta_{Death}(1-\nu_H) M_H^C$$

$$\frac{dR_H^C}{dt} = \delta I_H^C + \hat{\gamma} E_H^C + \delta_{Discharge}\nu_H M_H^C + \delta_{Death}(1-\nu_H) M_H^C - \alpha_H R_H^C + \psi_C R_H^P + \rho R_H^J$$

$$\frac{dS_O^C}{dt} = -\beta_{OK}^C S_O^C \left(I_K^C + \sigma E_K^C\right) - \beta_{OL}^C S_O^C \left(I_L^C + I_O^C + \sigma\left(E_L^C + E_O^C\right)\right) - \beta_{OE}^C S_O^C \left(I_E^C + \sigma E_E^C\right) - \beta_{OH}^C S_O^C \left(I_H^C + \sigma E_H^C\right) - \mu_J S_O^C + \mu_C S_O^J$$

$$\frac{dE_O^C}{dt} = \beta_{OK}^C S_O^C \left(I_K^C + \sigma E_K^C\right) + \beta_{OL}^C S_O^C \left(I_L^C + I_O^C + \sigma\left(E_L^C + E_O^C\right)\right) + \beta_{OE}^C S_O^C \left(I_E^C + \sigma E_E^C\right) + \beta_{OH}^C S_O^C \left(I_H^C + \sigma E_H^C\right) - (\gamma + \hat{\gamma}) E_O^C - \mu_J E_O^C + \mu_C E_O^J$$

$$\frac{dI_O^C}{dt} = \gamma E_O^C - \delta I_O^C - \omega_L I_O^C - \mu_J I_O^C + \mu_C I_O^J$$

$$\frac{dM_O^C}{dt} = \omega_L \left(I_O^C + I_O^J\right) - \delta_{Discharge}\nu M_O^C - \delta_{Death}(1-\nu) M_O^C$$

$$\frac{dR_O^C}{dt} = \delta I_O^C + \hat{\gamma} E_O^C + \delta_{Discharge}\nu M_O^C + \delta_{Death}(1-\nu) M_O^C - \mu_J R_O^C + \mu_C R_O^J$$

Within the Processing System:

$$\frac{dS_L^P}{dt} = -\beta_{LL}^P S_L^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{LE}^P S_L^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{LH}^P S_L^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \alpha_L S_L^C - \psi_C S_L^P - \psi_J S_L^P$$

$$\frac{dE_L^P}{dt} = \beta_{LL}^P S_L^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{LE}^P S_L^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{LH}^P S_L^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_L^P + \alpha_L E_L^C - \psi_C E_L^P - \psi_J E_L^P$$

$$\frac{dI_L^P}{dt} = \alpha_L I_L^C - \psi_C R_L^P - \psi_J R_L^P + \delta I_L^P + \hat{\gamma} E_L^P$$

$$\frac{dS_E^P}{dt} = -\beta_{EL}^P S_E^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{EE}^P S_E^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{EH}^P S_E^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \alpha_E S_E^C - \psi_C S_E^P - \psi_J S_E^P$$

$$\frac{dE_E^P}{dt} = \beta_{EL}^P S_E^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{EE}^P S_E^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{EH}^P S_E^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_E^P + \alpha_E E_E^C - \psi_C E_E^P - \psi_J E_E^P$$

$$\frac{dI_E^P}{dt} = \gamma E_E^P - \delta I_E^P + \alpha_E I_E^C - \psi_C I_E^P - \psi_J I_E^P$$

$$\frac{dR_E^P}{dt} = \alpha_E R_E^C - \psi_C R_E^P - \psi_J R_E^P + \delta I_E^P + \hat{\gamma} E_E^P$$

$$\frac{dS_H^P}{dt} = -\beta_{HL}^P S_H^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{HE}^P S_H^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{HH}^P S_H^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \alpha_H S_H^C - \psi_C S_H^P - \psi_J S_H^P$$

$$\frac{dE_H^P}{dt} = \beta_{HL}^P S_H^P \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{HE}^P S_H^P \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{HH}^P S_H^P \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_H^P + \alpha_H E_H^C - \psi_C E_H^P - \psi_J E_H^P$$

$$\frac{dI_H^P}{dt} = \gamma E_H^P - \delta I_H^P + \alpha_H I_H^C - \psi_C I_H^P - \psi_J I_H^P$$

$$\frac{dR_H^P}{dt} = \alpha_H R_H^C - \psi_C R_H^P - \psi_J R_H^P + \delta I_H^P + \hat{\gamma} E_H^P$$

Within the Trial System:

$$\frac{dS_L^T}{dt} = -\beta_{LL}^T S_L^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{LE}^T S_L^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{LH}^T S_L^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \kappa\tau S_L^J - \kappa S_L^T$$

$$\frac{dE_L^T}{dt} = \beta_{LL}^T S_L^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{LE}^T S_L^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{LH}^T S_L^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_L^T + \kappa\tau E_L^J - \kappa E_L^T$$

$$\frac{dI_L^T}{dt} = \gamma E_L^T - \delta I_L^T + \kappa\tau I_L^J - \kappa I_L^T$$

$$\frac{dR_L^T}{dt} = \kappa\tau R_L^J - \kappa R_L^T + \delta I_L^T + \hat{\gamma} E_L^T$$

$$\frac{dS_E^T}{dt} = -\beta_{EL}^T S_E^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{EE}^T S_E^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{EH}^T S_E^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \kappa\tau S_E^J - \kappa S_E^T$$

$$\frac{dE_E^T}{dt} = \beta_{EL}^T S_E^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{EE}^T S_E^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{EH}^T S_E^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_E^T + \kappa\tau E_E^J - \kappa E_E^T$$

$$\frac{dI_E^T}{dt} = \gamma E_E^T - \delta I_E^T + \kappa\tau I_E^J - \kappa I_E^T$$

$$\frac{dR_E^T}{dt} = \kappa\tau R_E^J - \kappa R_E^T + \delta I_E^T + \hat{\gamma} E_E^T$$

$$\frac{dS_H^T}{dt} = -\beta_{HL}^T S_H^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) - \beta_{HE}^T S_H^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) - \beta_{HH}^T S_H^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) + \kappa\tau S_H^J - \kappa S_H^T$$

$$\frac{dE_H^T}{dt} = \beta_{HL}^T S_H^T \left(I_L^P + I_L^T + \sigma\left(E_L^P + E_L^T\right)\right) + \beta_{HE}^T S_H^T \left(I_E^P + I_E^T + \sigma\left(E_E^P + E_E^T\right)\right) + \beta_{HH}^T S_H^T \left(I_H^P + I_H^T + \sigma\left(E_H^P + E_H^T\right)\right) - (\gamma + \hat{\gamma}) E_H^T + \kappa\tau E_H^J - \kappa E_H^T$$

$$\frac{dI_H^T}{dt} = \gamma E_H^T - \delta I_H^T + \kappa\tau I_H^J - \kappa I_H^T$$

$$\frac{dR_H^T}{dt} = \kappa\tau R_H^J - \kappa R_H^T + \delta I_H^T + \hat{\gamma} E_H^T$$

Within the Jail System:

$$\frac{dS_L^J}{dt} = -\beta_{LL}^J S_L^J \left(I_L^J + \sigma E_L^J\right) - \beta_{LE}^J S_L^J \left(I_E^J + \sigma E_E^J\right) - \beta_{LH}^J S_L^J \left(I_H^J + \sigma E_H^J\right) - \beta_{LO}^J S_L^J \left(I_O^J + \sigma E_O^J\right) + \psi_J S_L^P - \kappa\tau S_L^J - \rho S_L^J + \kappa S_L^T$$

$$\frac{dE_L^J}{dt} = \beta_{LL}^J S_L^J \left(I_L^J + \sigma E_L^J\right) + \beta_{LE}^J S_L^J \left(I_E^J + \sigma E_E^J\right) + \beta_{LH}^J S_L^J \left(I_H^J + \sigma E_H^J\right) + \beta_{LO}^J S_L^J \left(I_O^J + \sigma E_O^J\right) - (\gamma + \hat{\gamma}) E_L^J + \psi_J E_L^P - \kappa\tau E_L^J - \rho E_L^J + \kappa E_L^T$$

$$\frac{dI_L^J}{dt} = \gamma E_L^J - \delta I_L^J - \omega_L \zeta I_L^J - (1-\nu_U)(1-\zeta)\delta_{Death_U} I_L^J - \nu_U (1-\zeta)\delta_{Discharge} I_L^J + \psi_J I_L^P - \kappa\tau I_L^J - \rho I_L^J + \kappa I_L^T$$

$$\frac{dM_L^J}{dt} = \omega_L \zeta I_L^J - \delta_{Discharge}\nu M_L^J - \delta_{Death}(1-\nu) M_L^J$$

$$\frac{dR_L^J}{dt} = \delta I_L^J + \hat{\gamma} E_L^J + \delta_{Discharge}\nu M_L^J + \delta_{Death}(1-\nu) M_L^J + \delta_{Death_U}(1-\nu_U)(1-\zeta) I_L^J + \delta_{Discharge}\nu_U (1-\zeta) I_L^J + \psi_J R_L^P - \kappa\tau R_L^J - \rho R_L^J + \kappa R_L^T$$

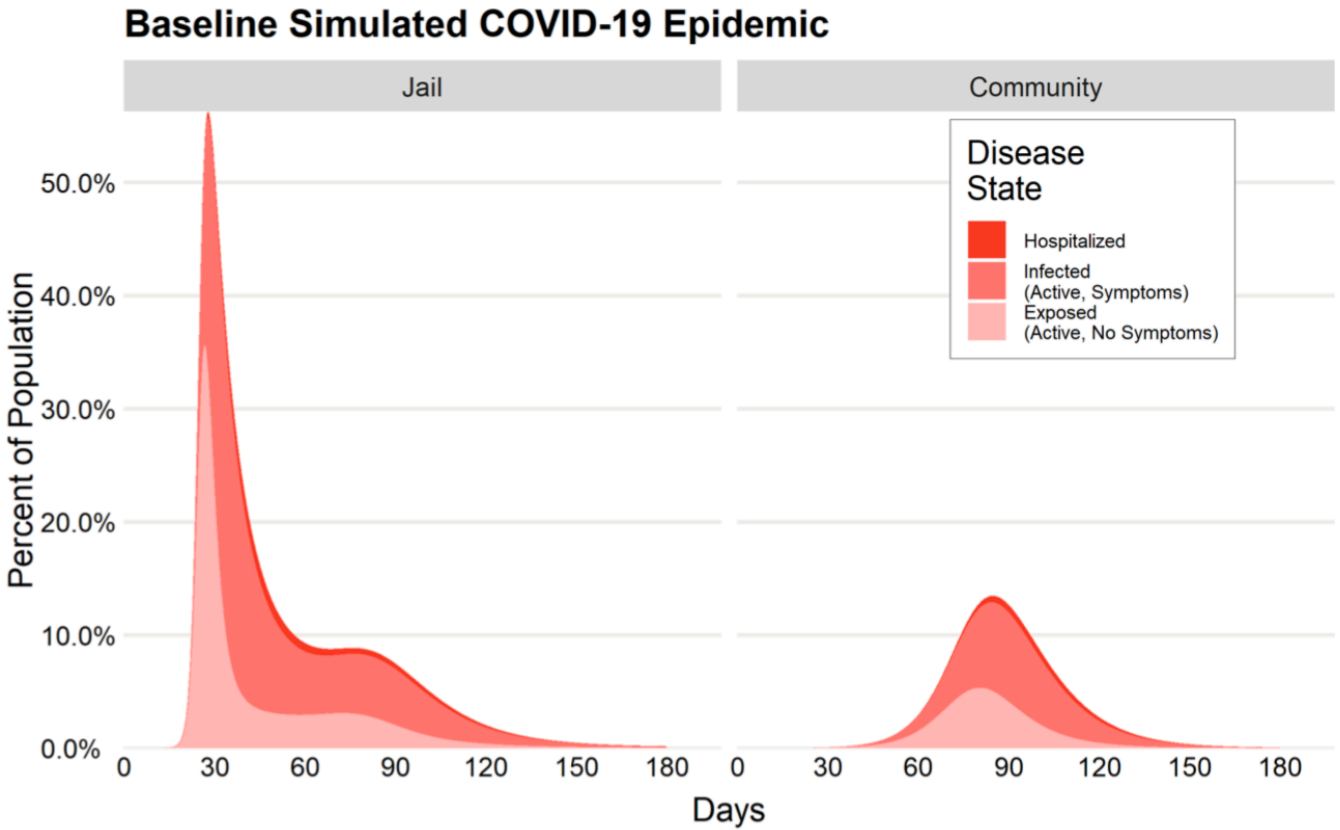
$$\frac{dS_E^J}{dt} = -\beta_{EL}^J S_E^J \left(I_L^J + \sigma E_L^J\right) - \beta_{EE}^J S_E^J \left(I_E^J + \sigma E_E^J\right) - \beta_{EH}^J S_E^J \left(I_H^J + \sigma E_H^J\right) - \beta_{EO}^J S_E^J \left(I_O^J + \sigma E_O^J\right) + \psi_J S_E^P - \kappa\tau S_E^J - \rho S_E^J + \kappa S_E^T$$

$$\frac{dE_E^J}{dt} = \beta_{EL}^J S_E^J \left(I_L^J + \sigma E_L^J\right) + \beta_{EE}^J S_E^J \left(I_E^J + \sigma E_E^J\right) + \beta_{EH}^J S_E^J \left(I_H^J + \sigma E_H^J\right) + \beta_{EO}^J S_E^J \left(I_O^J + \sigma E_O^J\right) - (\gamma + \hat{\gamma}) E_E^J + \psi_J E_E^P - \kappa\tau E_E^J - \rho E_E^J + \kappa E_E^T$$

A complex epidemiological model in R

```
with (
  as.list(params),
  {
    dSk <- -Bkk*Sk*(Ik+sigma*Ek) - Blck*Sk*(Ilc+Ioc+sigma*(Elc+Eoc)) - Beck*Sk*(Iec+sigma*Eec) - Bhck*Sk*(Ihc+sigma*Ehc)
    dEk <- Bkk*Sk*(Ik+sigma*Ek) + Blck*Sk*(Ilc+Ioc+sigma*(Elc+Eoc)) + Beck*Sk*(Iec+sigma*Eec) + Bhck*Sk*(Ihc+sigma*Ehc) - gamma*Ek - gamma*Ek
    dIk <- gamma*Ek - quarantine_speedup_community*delta*Ik
    dRk <- quarantine_speedup_community*delta*Ik + gamma*Ik

    dSlc <- -Bklc*Slc*(Ik+sigma*Ek) - Blclc*Slc*(Ilc+Ioc+sigma*(Elc+Eoc)) - Beclc*Slc*(Iec+sigma*Eec) - Bhclc*Slc*(Ihc+sigma*Ehc) - alphaL*Slc + psiC*Slp + rho*Slj
    dElc <- Bklc*Slc*(Ik+sigma*Ek) + Blclc*Slc*(Ilc+Ioc+sigma*(Elc+Eoc)) + Beclc*Slc*(Iec+sigma*Eec) + Bhclc*Slc*(Ihc+sigma*Ehc) - gamma*Elc - gammaA*Elc -alphaL*Elc + psiC*
    dIlc <- gamma*Elc - quarantine_speedup_community*delta*Ilc - omega*Ilc - alphaL*Ilc + psiC*Ilp + rho*Ilj
    dHlc <- omega*Ilc - delta_death*(1-nu)*Hlc - delta_discharge*nu*Hlc
    dRlc <- quarantine_speedup_community*delta*Ilc + gammaA*Elc + delta_death*(1-nu)*Hlc + delta_discharge*nu*Hlc - alphaL*Rlc + psiC*Rlp + rho*Rlj

    dSec <- -Bkec*Sec*(Ik+sigma*Ek) - Blcec*Sec*(Ilc+Ioc+sigma*(Elc+Eoc)) - Becec*Sec*(Iec+sigma*Eec) - Bhcec*Sec*(Ihc+sigma*Ehc) - alphaE*Sec + psiC*Sep + rhoH*Sej
    dEec <- Bkec*Sec*(Ik+sigma*Ek) + Blcec*Sec*(Ilc+Ioc+sigma*(Elc+Eoc)) + Becec*Sec*(Iec+sigma*Eec) + Bhcec*Sec*(Ihc+sigma*Ehc) - gamma*Eec - gammaA*Eec - alphaE*Eec + psiC
    dIec <- gamma*Eec - quarantine_speedup_community*delta*Iec - omegaH*Iec - alphaE*Iec + psiC*Iep + rhoH*Iej
    dHec <- omegaH*Iec - delta_death*(1-nuH)*Hec - delta_discharge*nuH*Hec
    dRec <- quarantine_speedup_community*delta*Iec + gammaA*Eec + delta_death*(1-nuH)*Hec + delta_discharge*nuH*Hec - alphaE*Rec + psiC*Rep + rhoH*Rej

    dShc <- -Bkhc*Shc*(Ik+sigma*Ek) - Blchc*Shc*(Ilc+Ioc+sigma*(Elc+Eoc)) - Bechc*Shc*(Iec+sigma*Eec) - Bhchc*Shc*(Ihc+sigma*Ehc) - alphaH*Shc + psiC*Shp + rhoH*Shj
    dEhc <- Bkhc*Shc*(Ik+sigma*Ek) + Blchc*Shc*(Ilc+Ioc+sigma*(Elc+Eoc)) + Bechc*Shc*(Iec+sigma*Eec) + Bhchc*Shc*(Ihc+sigma*Ehc) - gamma*Ehc - gammaA*Ehc - alphaH*Ehc + psiC
    dIhc <- gamma*Ehc - quarantine_speedup_community*delta*Ihc - omegaH*Ihc - alphaH*Ihc + psiC*Ihp + rhoH*Ihj
    dHhc <- omegaH*Ihc - delta_death*(1-nuH)*Hhc - delta_discharge*nuH*Hhc
    dRhc <- quarantine_speedup_community*delta*Ihc + gammaA*Ehc + delta_death*(1-nuH)*Hhc + delta_discharge*nuH*Hhc - alphaH*Rhc + psiC*Rhp + rhoH*Rhj

    dSoc <- muC*Soj - muJ*Soc - Bkoc*Soc*(Ik+sigma*Ek) - Blcoc*Soc*(Ilc+Ioc+sigma*(Elc+Eoc)) - Becoc*Soc*(Iec+sigma*Eec) - Bhcoc*Soc*(Ihc+sigma*Ehc)
    dEoc <- muC*Eoj - muJ*Eoc + Bkoc*Soc*(Ik+sigma*Ek) + Blcoc*Soc*(Ilc+Ioc+sigma*(Elc+Eoc)) + Becoc*Soc*(Iec+sigma*Eec) + Bhcoc*Soc*(Ihc+sigma*Ehc) - gamma*Eoc - gammaA*Eoc
    dIoc <- muC*Ioj  -muJ*Ioc + gamma*Eoc - quarantine_speedup_community*delta*Ioc - omega*Ioc
    dHoc <- omega*(Ioc+Ioj) - delta_death*(1-nu)*Hoc - delta_discharge*nu*Hoc
    dRoc <- muC*Roj - muJ*Roc + quarantine_speedup_community*delta*Ioc + gammaA*Eoc + delta_death*(1-nu)*Hoc + delta_discharge*nu*Hoc

    dSlp <- alphaL*Slc - psiC*Slp - psiJ*Slp - Blplp*Slp*(Ilp+Ilt+sigma*(Elp+Elt)) - Beplp*Slp*(Iep+Iet+sigma*(Eep+Eet)) - Bhplp*Slp*(Ihp+Iht+sigma*(Ehp+Eht))
    dElp <- alphaL*Elc - psiC*Elp - psiJ*Elp + Blplp*Slp*(Ilp+Ilt+sigma*(Elp+Elt)) + Beplp*Slp*(Iep+Iet+sigma*(Eep+Eet)) + Bhplp*Slp*(Ihp+Iht+sigma*(Ehp+Eht)) - gamma*Elp -
    dIlp <- alphaL*Ilc - psiC*Ilp - psiJ*Ilp + gamma*Elp - quarantine_speedup_jail*delta*Ilp
    dRlp <- alphaL*Rlc - psiC*Rlp - psiJ*Rlp + quarantine_speedup_jail*delta*Ilp + gammaA*Elp

    dSep <- alphaE*Sec - psiC*Sep - psiJ*Sep - Blpep*Sep*(Ilp+Ilt+sigma*(Elp+Elt)) - Bepep*Sep*(Iep+Iet+sigma*(Eep+Eet)) - Bhpep*Sep*(Ihp+Iht+sigma*(Ehp+Eht))
    dEep <- alphaE*Eec - psiC*Eep - psiJ*Eep + Blpep*Sep*(Ilp+Ilt+sigma*(Elp+Elt)) + Bepep*Sep*(Iep+Iet+sigma*(Eep+Eet)) + Bhpep*Sep*(Ihp+Iht+sigma*(Ehp+Eht)) - gamma*Eep -
    dIep <- alphaE*Iec - psiC*Iep - psiJ*Iep + gamma*Eep - quarantine_speedup_jail*delta*Iep
    dRep <- alphaE*Rec - psiC*Rep - psiJ*Rep + quarantine_speedup_jail*delta*Iep + gammaA*Eep

    dShp <- alphaH*Shc - psiC*Shp - psiJ*Shp - Blphp*Shp*(Ilp+Ilt+sigma*(Elp+Elt)) - Bephp*Shp*(Iep+Iet+sigma*(Eep+Eet)) - Bhphp*Shp*(Ihp+Iht+sigma*(Ehp+Eht))
    dEhp <- alphaH*Ehc - psiC*Ehp - psiJ*Ehp + Blphp*Shp*(Ilp+Ilt+sigma*(Elp+Elt)) + Bephp*Shp*(Iep+Iet+sigma*(Eep+Eet)) + Bhphp*Shp*(Ihp+Iht+sigma*(Ehp+Eht)) - gamma*Ehp -
    dIhp <- alphaH*Ihc - psiC*Ihp - psiJ*Ihp + gamma*Ehp - quarantine_speedup_jail*delta*Ihp
    dRhp <- alphaH*Rhc - psiC*Rhp - psiJ*Rhp + quarantine_speedup_jail*delta*Ihp + gammaA*Ehp
```

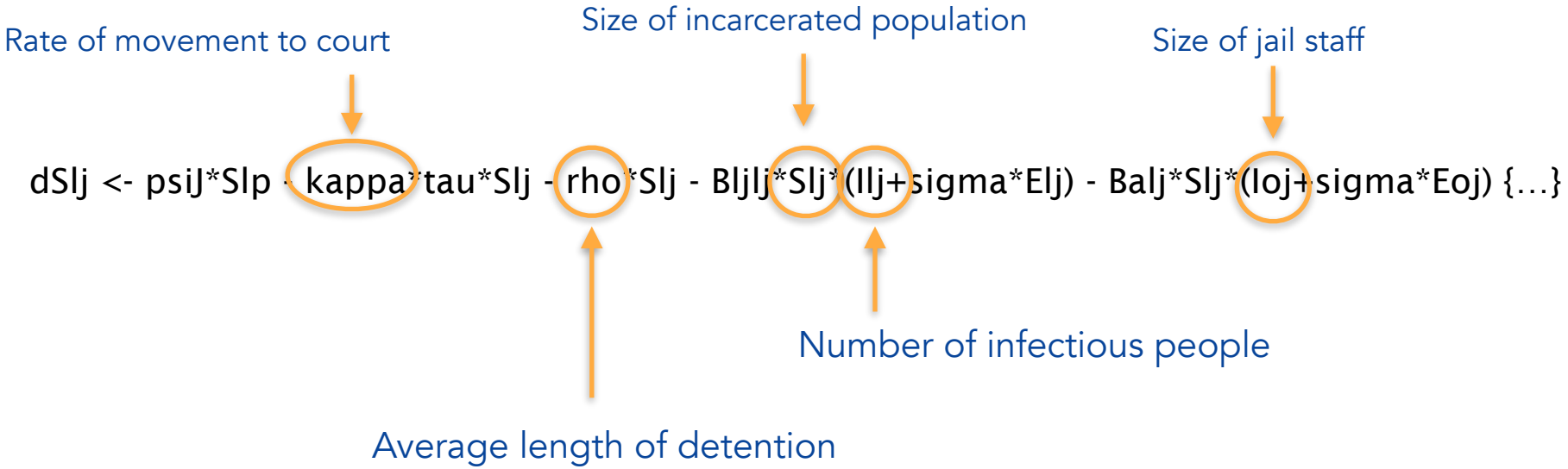
```
dSlj <- psiJ*Slp - kappa*tau*Slj - rho*Slj - Bljlj*Slj*(Ilj+sigma*Elj) - Bejlj*S
dElj <- psiJ*Elp - kappa*tau*Elj - rho*Elj + Bljlj*Slj*(Ilj+sigma*Elj) + Bejlj*S
dIlj <- psiJ*Ilp - kappa*tau*Ilj - rho*Ilj + gamma*Elj - quarantine_speedup_jail
dHlj <- omega*zeta*Ilj - delta_death*(1-nu)*Hlj - delta_discharge*nu*Hlj
dRlj <- kappa*tau*Rlp - rho*Rlj + quarantine_speedup_jail*delta*Ilj +

dSej <- psiJ*Sep - kappa*tau*Sej - rhoH*Sej - Bljej*Sej*(Ilj+sigma*Elj) - Bejej*
dEej <- psiJ*Eep - kappa*tau*Eej - rhoH*Eej + Bljej*Sej*(Ilj+sigma*Elj) + Bejej*
dIej <- psiJ*Iep - kappa*tau*Iej - rhoH*Iej + gamma*Eej - quarantine_speedup_jai
dHej <- omegaH*zeta*Iej - delta_death*(1-nuH)*Hej - delta_discharge*nuH*Hej
dRej <- psiJ*Rep - kappa*tau*Rej - rhoH*Rej + quarantine_speedup_jail*delta*Iej

dShj <- psiJ*Shp - kappa*tau*Shj - rhoH*Shj - Bljhj*Shj*(Ilj+sigma*Elj) - Bejhj*
dEhj <- psiJ*Ehp - kappa*tau*Ehj - rhoH*Ehj + Bljhj*Shj*(Ilj+sigma*Elj) + Bejhj*
dIhj <- psiJ*Ihp - kappa*tau*Ihj - rhoH*Ihj + gamma*Ehj - quarantine_speedup_jai
dHhj <- omegaH*zeta*Ihj - delta_death*(1-nuH)*Hhj - delta_discharge*nuH*Hhj
dRhj <- psiJ*Rhp - kappa*tau*Rhj - rhoH*Rhj + quarantine_speedup_jail*delta*Ihj

dSlt <- kappa*tau*Slj - kappa*Slt - Blplt*Slt*(Ilp+Ilt+sigma*(Elp+Elt)) - Beplt*
dElt <- kappa*tau*Elj - kappa*Elt + Blplt*Slt*(Ilp+Ilt+sigma*(Elp+Elt)) + Beplt*
dIlt <- kappa*tau*Ilj - kappa*Ilt + gamma*Elt - quarantine_speedup_jail*delta*Il
dRlt <- kappa*tau*Rlj - kappa*Rlt + quarantine_speedup_jail*delta*Ilt + gammaA*E

dSet <- kappa*tau*Sej - kappa*Set - Blpet*Set*(Ilp+Ilt+sigma*(Elp+Elt)) - Bepet*
dEet <- kappa*tau*Eej - kappa*Eet + Blpet*Set*(Ilp+Ilt+sigma*(Elp+Elt)) + Bepet*
dIet <- kappa*tau*Iej - kappa*Iet + gamma*Eet - quarantine_speedup_jail*delta*Ie
dRet <- kappa*tau*Rej - kappa*Ret + quarantine_speedup_jail*delta*Iet + gammaA*E

dSht <- kappa*tau*Shj - kappa*Sht - Blpht*Sht*(Ilp+Ilt+sigma*(Elp+Elt)) - Bepht*
dEht <- kappa*tau*Ehj - kappa*Eht + Blpht*Sht*(Ilp+Ilt+sigma*(Elp+Elt)) + Bepht*
dIht <- kappa*tau*Ihj - kappa*Iht + gamma*Eht - quarantine_speedup_jail*delta*Ih
dRht <- kappa*tau*Rhj - kappa*Rht + quarantine_speedup_jail*delta*Iht + gammaA*E

dSoj <- muJ*Soc - muC*Soj -  Baoj*Soj*(Ilj+Iej+Ihj+sigma*(Elj+Eej+Ehj)) -   Bojo
dEoj <- muJ*Eoc - muC*Eoj +  Baoj*Soj*(Ilj+Iej+Ihj+sigma*(Elj+Eej+Ehj)) +   Bojo
dIoj <- muJ*Ioc - muC*Ioj + gamma*Eoj - omega*Ioj - quarantine_speedup_jail*delt
dRoj <- muJ*Roc - muC*Roj + quarantine_speedup_jail*delta*Ioj + gammaA*Eoj
```


Baseline Simulated COVID-19 Epidemic
Jail
Community
Disease State
Hospitalized
Infected (Active, Symptoms)
Exposed (Active, No Symptoms)
Percent of Population
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0
30
60
90
120
150
180
Days

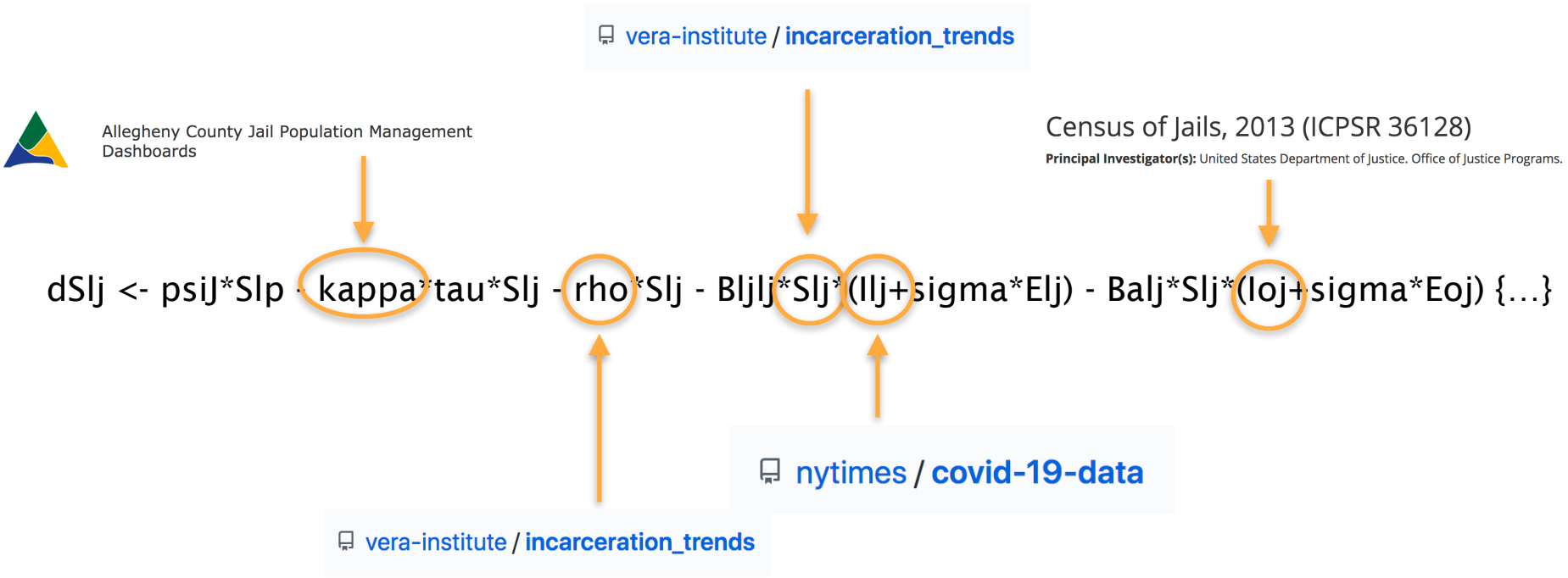
Modeling 1,242 outbreaks

Challenge #1: parameterizing to data from localities

Many pieces of the equation can be parameterized to local settings.



Solution #1: open, public data



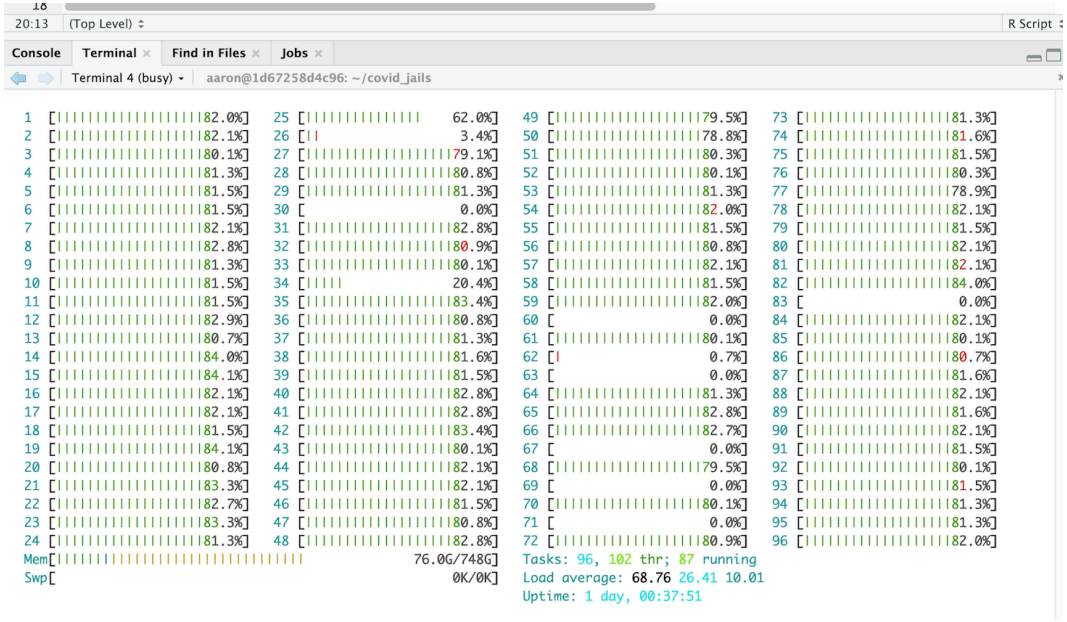
Challenge #2: parallelizing

We ran each model for 4,320 hours across 6 scenarios with 3 sets of assumptions each.

This is manageable for one locality, but across 1,242 jurisdictions, this is over **96 million rows** of simulation output 👀

Solution #2: future + furrr

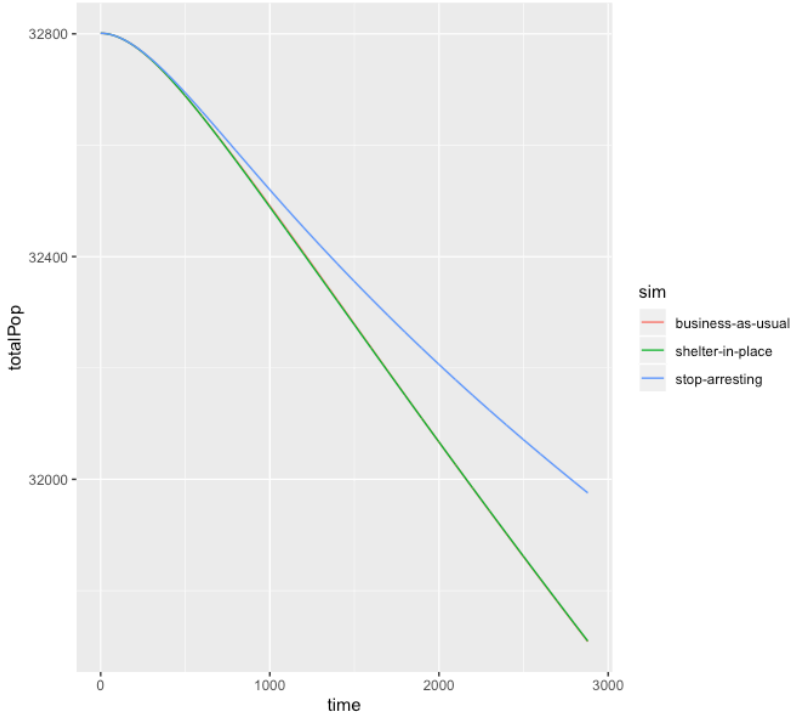
The {future} + {furrr} packages allowed us to run dozens of models at the same time across a massive (temporary) EC2 instance, using tidyverse syntax



```
scenarios_df <- purrr::map2_df(
                          .x = scenarios_list,
                          .y = names(scenarios_list),
                          .f = ~tidy_covid_run(xstart =.x$xstart,
                                               params = .x$params,
                                               .n_days = .x$n_days,  #ndays need to be same length as parameters!
                                               run_name = .y,
                                               .atol = 1e-6,
                                               .rtol = 1e-6
                                               )
                          ) %>%
  mutate(location_id = location_name)
```

```
res <- furrr::future_map_dfr(.x = as.list(data_list)$data, .progress = TRUE,
                             .f = ~.x %>%
                               rowwise() %>%
                               do(output = run_full_suite(.processing_pop = .$processing_population,
                                                          .pop = .$total_population,
                                                          .jail_pop = .$jail_daily_population,
                                                          .jail_staff = .$jail_staff_population,
                                                          .daily_arrests =.$daily_arrests,
                                                          .daily_releases = .$daily_releases,
                                                          .n_days = c(.$burn_in_days,.$delay_days,.$remaining_days),
                                                          location_name = .$id,
                                                          version_name = version_name,
                                                          .sip = .$sip,
                                                          .arrest_reduction = .$arrest_reduction
                                                          )) %>%
                               unnest(col = c(output))
                             )
```

Challenge #3: testing at scale



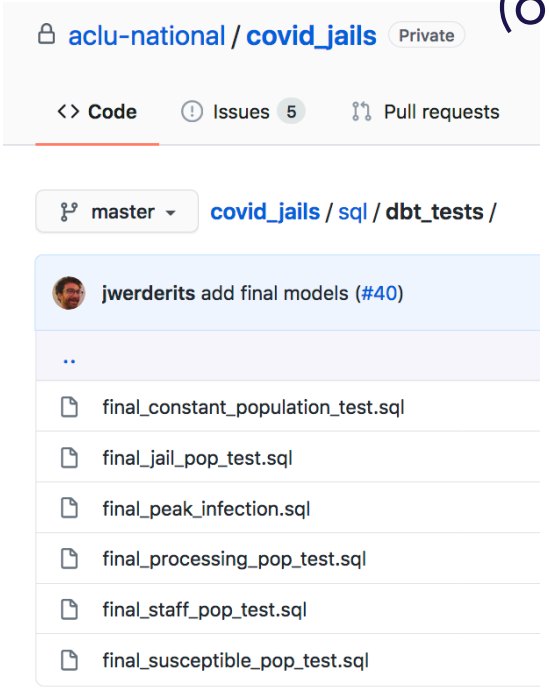
In early stages, we tested with pictures.

In one early model iteration, **-kappa*SIt** was not paired with a corresponding **kappa*SIt.**, leading people to simply vanish from trial proceedings.

Testing visually isn't feasible with over 20,000 models.

Solution #3: bring in the data engineers

(or at least the data engineering best practices)



10 lines (10 sloc) | 246 Bytes

```sql
--total population stays constant test
with calc as (
        select
        location_id,
        count(distinct total_population) as duplicated_pops
    from {{ ref('fct_covid_national') }}
    group by 1
)
select * from calc
where duplicated_pops > 1
```

Challenge #4: imputation bugs

Aaron Horowitz 🥶 3:07 PM

hmmm, i defintely am not seeing that....

Aaron Horowitz 🥶 3:13 PM

oh my [redacted.] i think this could be setting seeds issue?!

Solution #4: set.seed()

```
library(simputation)
library(tidyverse)

imputed_staff <- simputation::impute_knn(
    as.data.frame(jail_full_prep),
        staff_2013 ~ jail_daily_population +
                        total_population,
        pool = "multivariate"
)
```

```
set.seed(8)

library(simputation)
library(tidyverse)

imputed_staff <- simputation::impute_knn(
    as.data.frame(jail_full_prep),
        staff_2013 ~ jail_daily_population +
                        total_population,
        pool = "multivariate"
)
```

Results

Conducting Original Research: Simulating the spread of COVID-19 in jails

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The Epidemiological Implications of Incarceration Dynamics in Jails for Community, Corrections Officer, and Incarcerated Population Risks from COVID-19

Eric Lofgren, Kristian Lum, Aaron Horowitz, Brooke Madubuonwu, Nina Fefferman

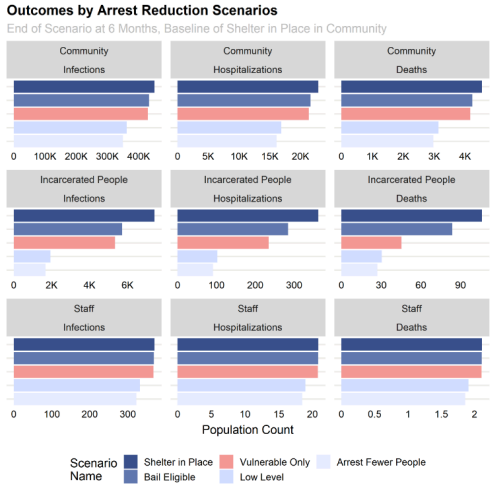
doi: https://doi.org/10.1101/2020.04.08.20058842

This article is a preprint and has not been peer-reviewed [what does this mean?]. It reports new medical research that has yet to be evaluated and so should *not* be used to guide clinical practice.

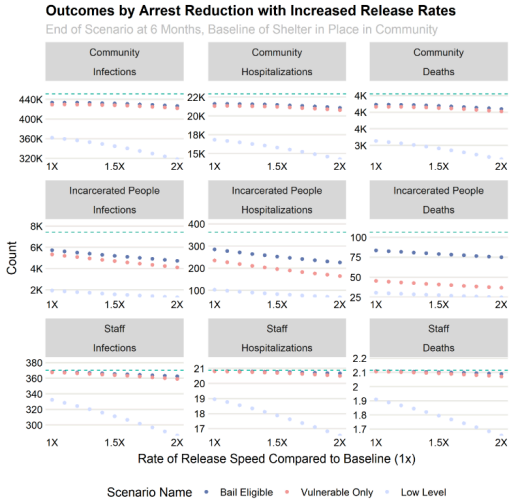
Abstract | Info/History | Metrics | Preview PDF

COVID-19 in jails: main interventions explored

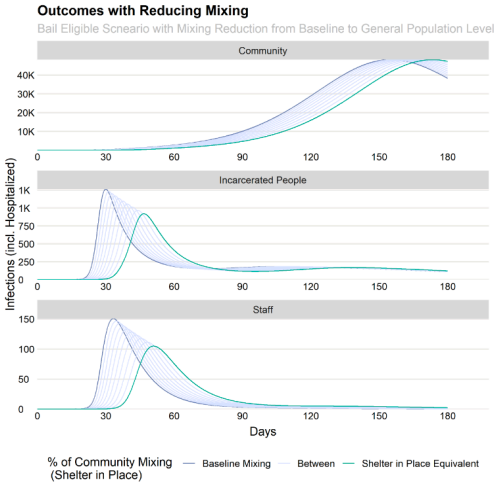
Reducing intake (arrests)



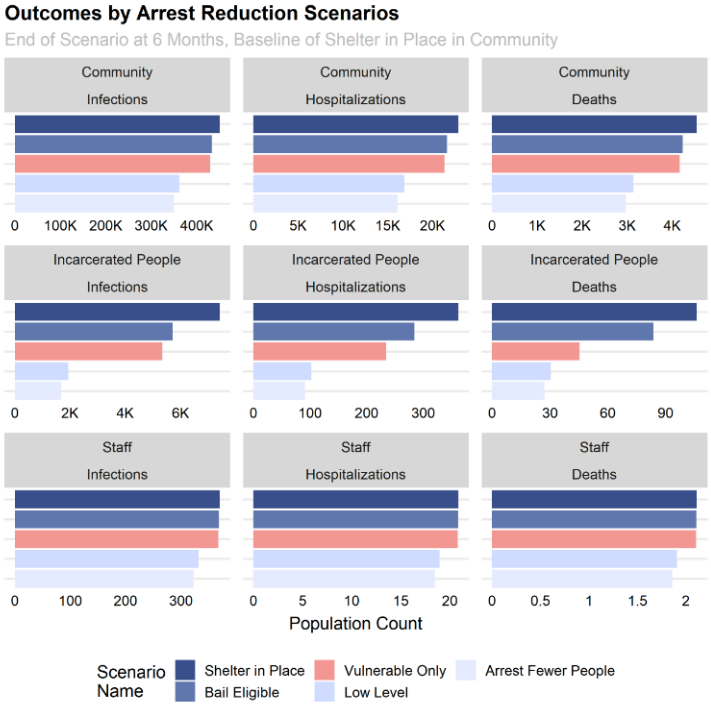
Reducing arrests + increasing releases



Reducing effective contact rates within jails

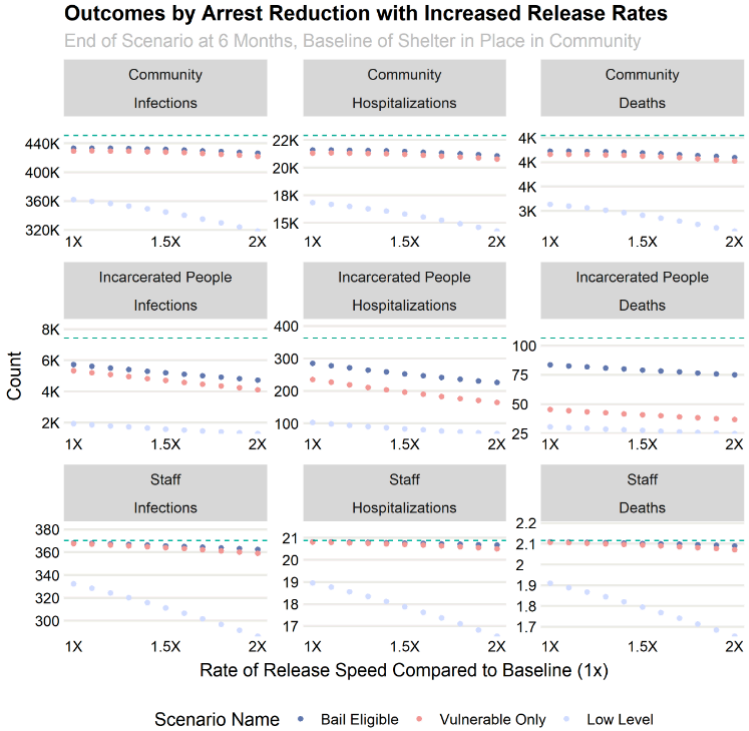


COVID-19 in jails: main findings



The best way to reduce jail transmission is to **reduce arrests + bookings as much as possible.** This is not exclusive to medically vulnerable people: more people in jail means more people capable of catching & spreading the virus.

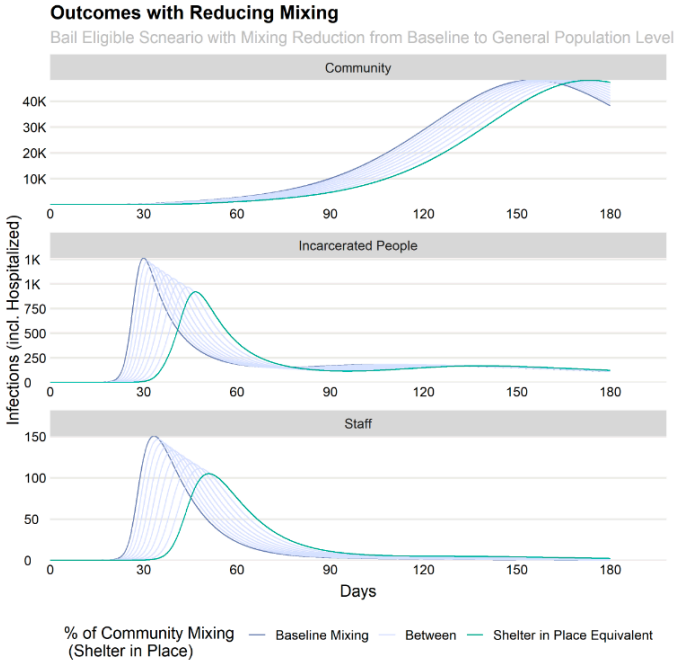
COVID-19 in jails: main findings



Faster rates of release, paired with arrest reductions, reduce cases and deaths in jails and in the communities.

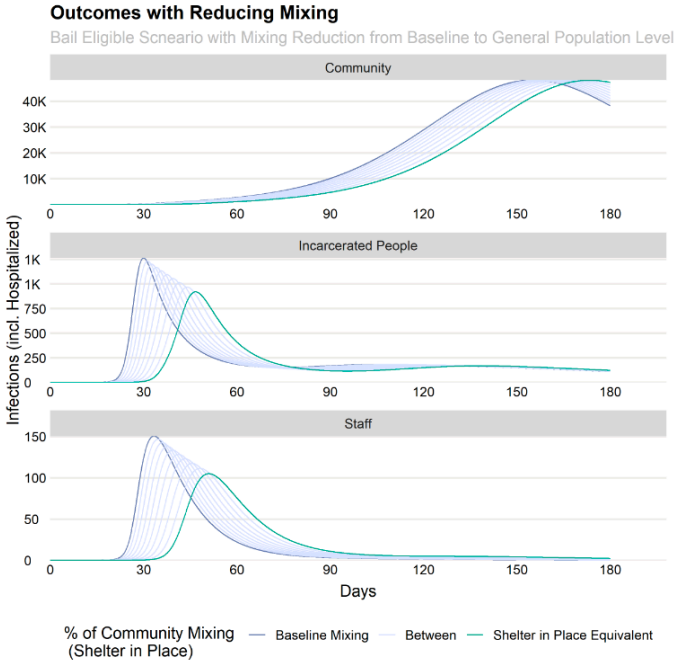
Allowing **medically vulnerable people to return home** is a particularly life-saving intervention.

COVID-19 in jails: main findings



Reduction of the effective contact rate, (e.g. by improving sanitation and hygiene, providing masks, and adding spaces for social distancing in jails and prisons) **is necessary and essential, but not enough to stop transmission**.

COVID-19 in jails: main findings

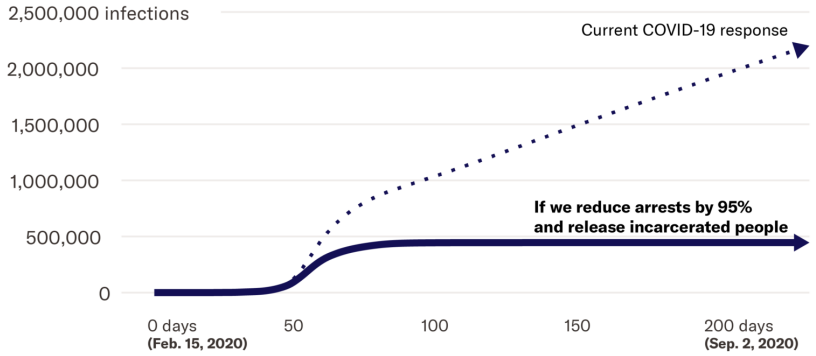


Improving sanitation and hygiene, and adding spaces for social distancing in jails and prisons is necessary and essential, but not enough with current population sizes.

Reducing arrests saves lives.

COVID-19 INFECTIONS IN JAILS UNDER CURRENT RESPONSE

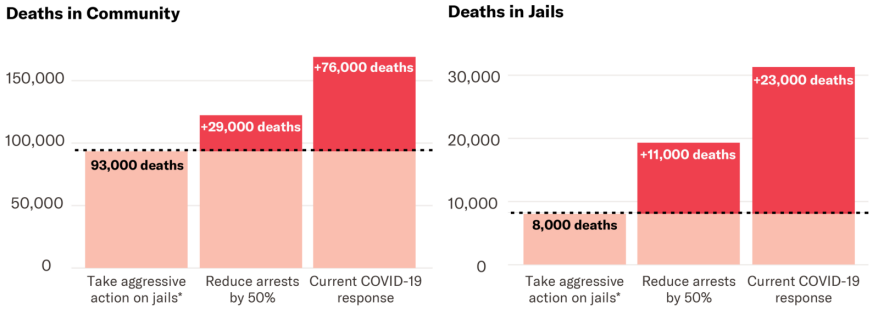
Jails could see more infections, hospitalizations, and deaths under the current response. These higher infection rates could spill over into the broader community.



Note: Estimates of infections are cumulative, and jail staff are included in count. "Current response" refers to the shelter in place orders in effect as of April 13, 2020. We recommend stopping 95% of arrests — all but the most serious crimes — and doubling the rate of release for those currently detained.

COVID-19 DEATHS BY PUBLIC RESPONSE

Including incarcerated people in our public health response could reduce the death toll in both jails and the general public.



Note: "Current response" refers to the shelter in place orders in effect as of April 13, 2020. *We recommend stopping 95% of arrests — all but the most serious crimes — and doubling the rate of release for those currently detained. Jail staff are included in estimated deaths.

Impact

HealthAffairs

TOPICS JOURNAL BLOG BRIEFS

RESEARCH ARTICLE COVID-19

HEALTH AFFAIRS > VOL. 39, NO. 8: COVID-19, HOME HEALTH & MORE

Incarceration And Its Disseminations: COVID-19 Pandemic Lessons From Chicago's Cook County Jail

Eric Reinhart and Daniel L. Chen

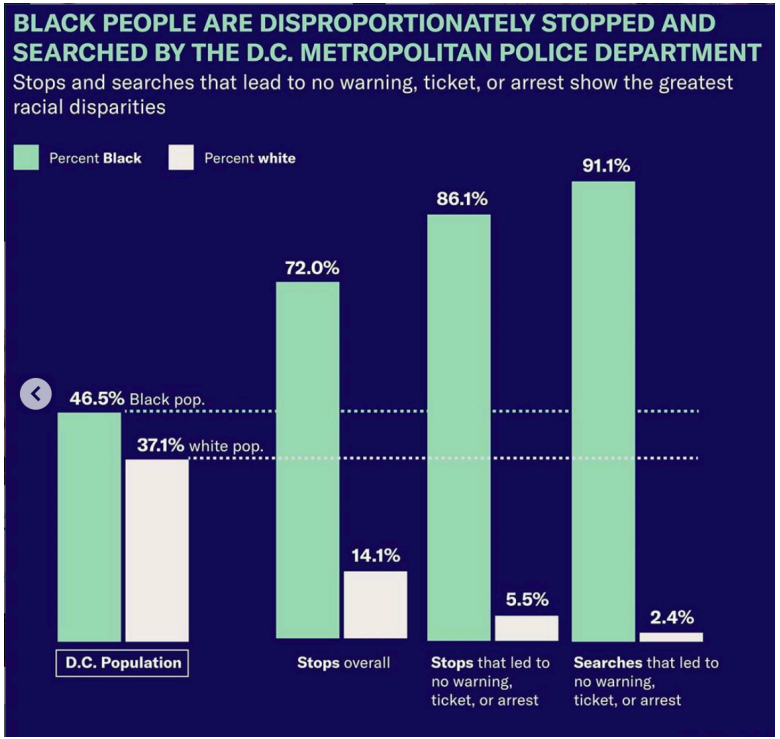
ZIP code level. We found that jail–community cycling was a significant predictor of cases of coronavirus disease 2019 (COVID-19), accounting for 55 percent of the variance in case rates across ZIP codes in Chicago and

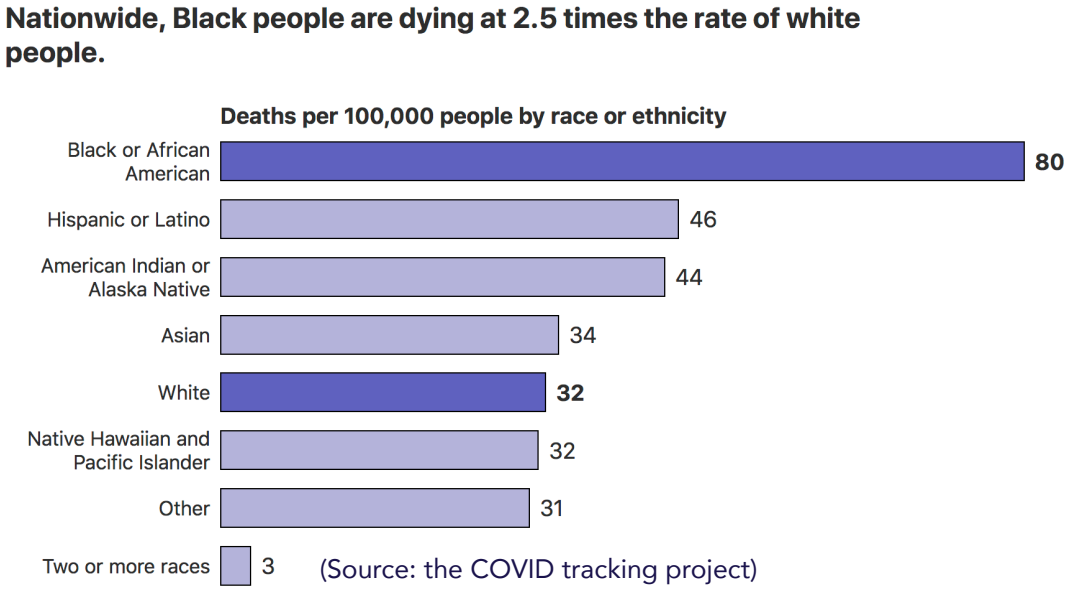
Incarceration Weakens a Community's Immune System: Mass Incarceration and COVID-19 Cases in Milwaukee

Preliminary Results

MEASURES FOR JUSTICE

Racial disparities in law enforcement contribute to racial disparities in COVID-19 cases and deaths.





As of mid-July 2020, the ACLU & affiliates had

- Filed **69 COVID-19 legal actions in jails and prisons**, 32 of which were class action lawsuits
- Filed **51 lawsuits in immigration detention**
- Successfully advocated with partners for the release from detention of over **48,000 individuals**

Thank you!

Report:
aclu.org/covidinjails

Slides:
github.com/brooke-watson/nyr-2020

Contact:
Twitter @brooklynevery1

ACLU