Exploring optimal vaccine allocation using a national model of influenza

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Questions

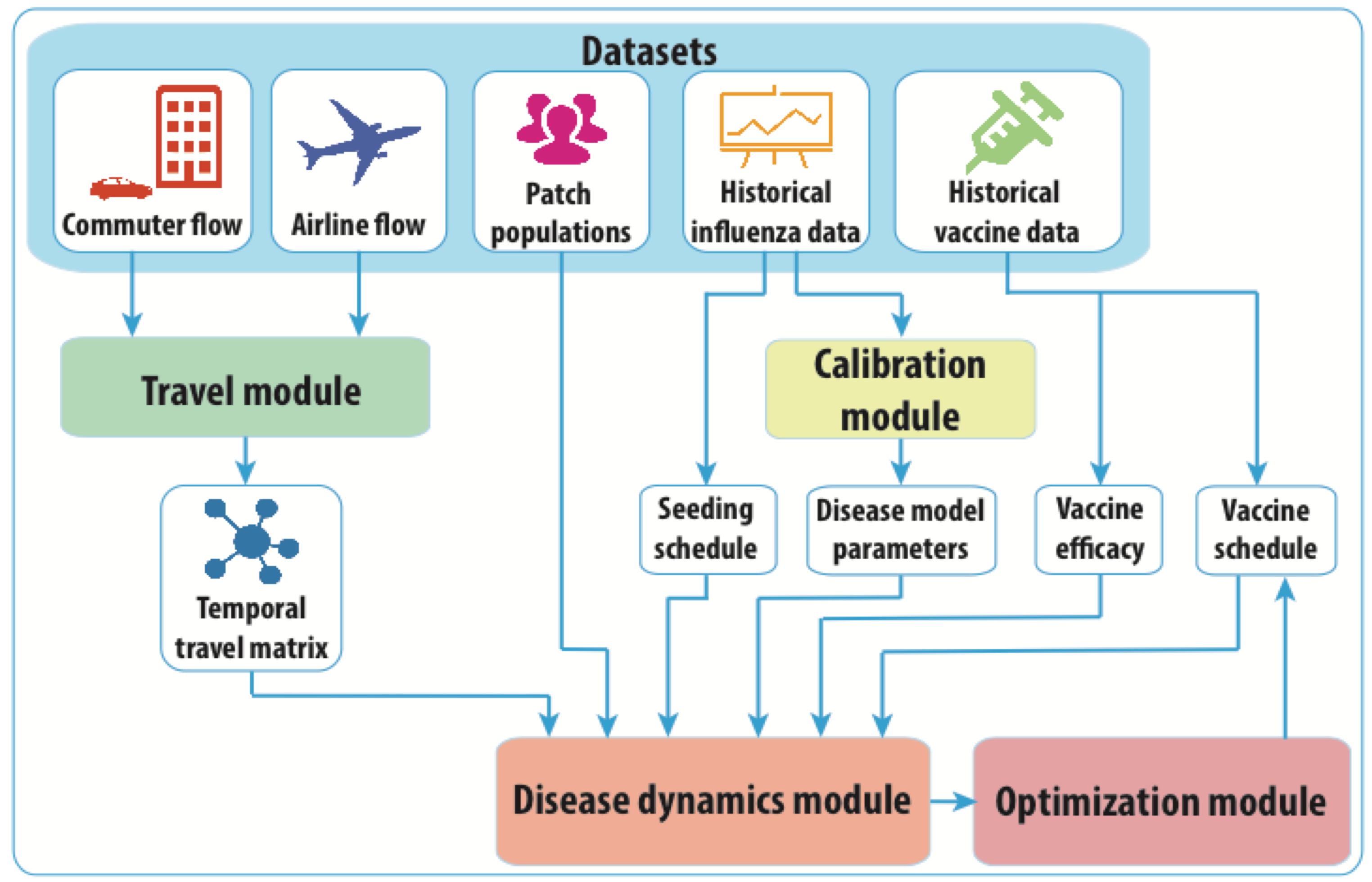
Can we optimize the allocation of vaccines to minimize the epidemic impact of seasonal/pandemic influenza?

Can we model the spatiotemporal spread of the epidemic?

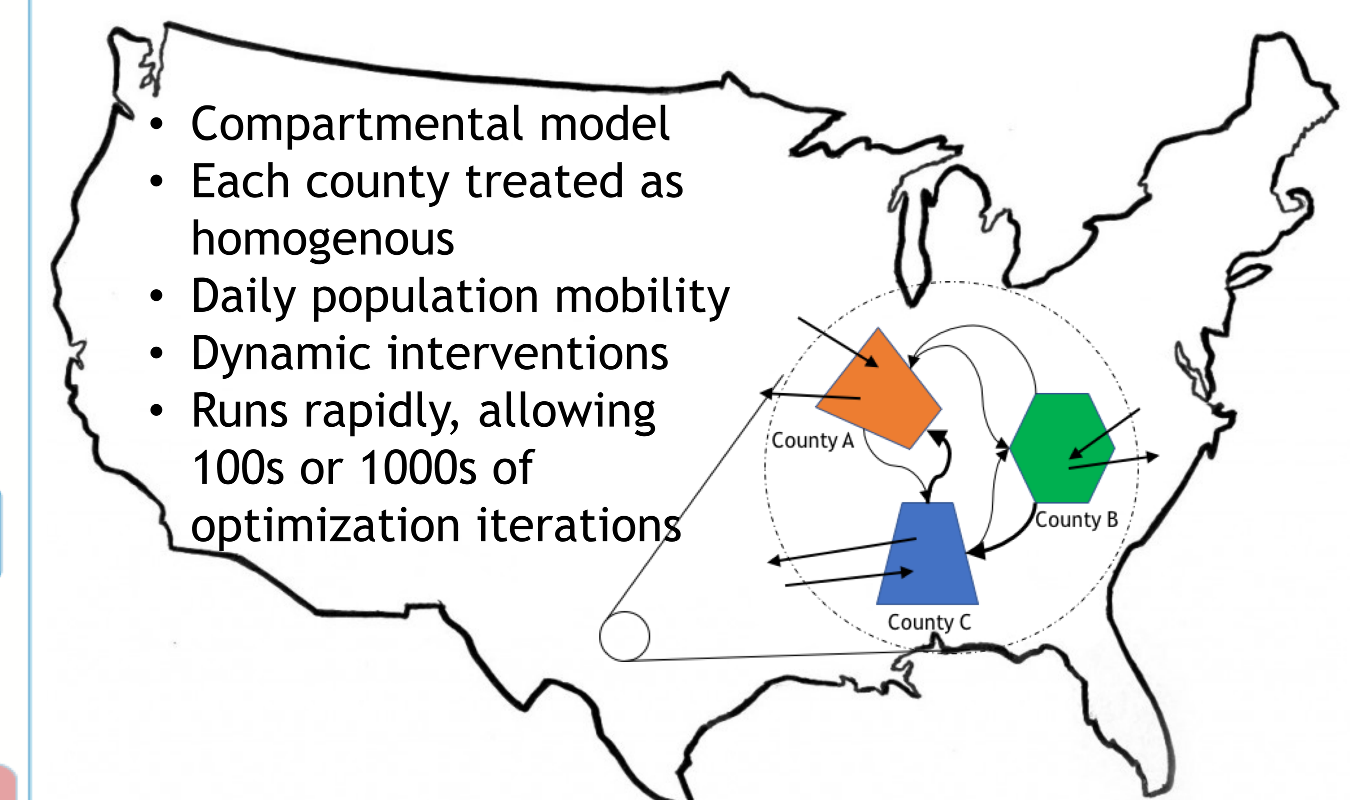
Can we capture human mobility at the national scale?

National Influenza Spread Model

Simulation Framework



National Spread Model

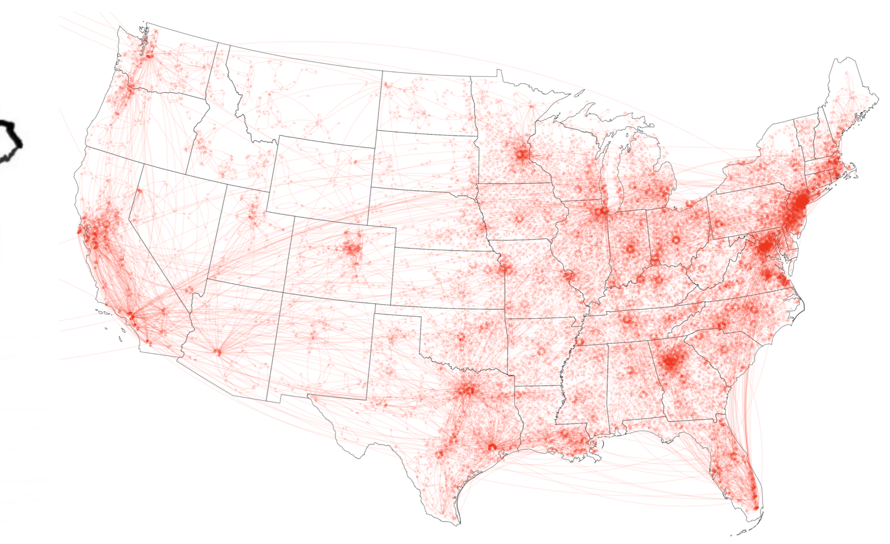


- Compartmental model
- Each county treated as homogenous
- Daily population mobility
- Dynamic interventions
- Runs rapidly, allowing 100s or 1000s of optimization iterations

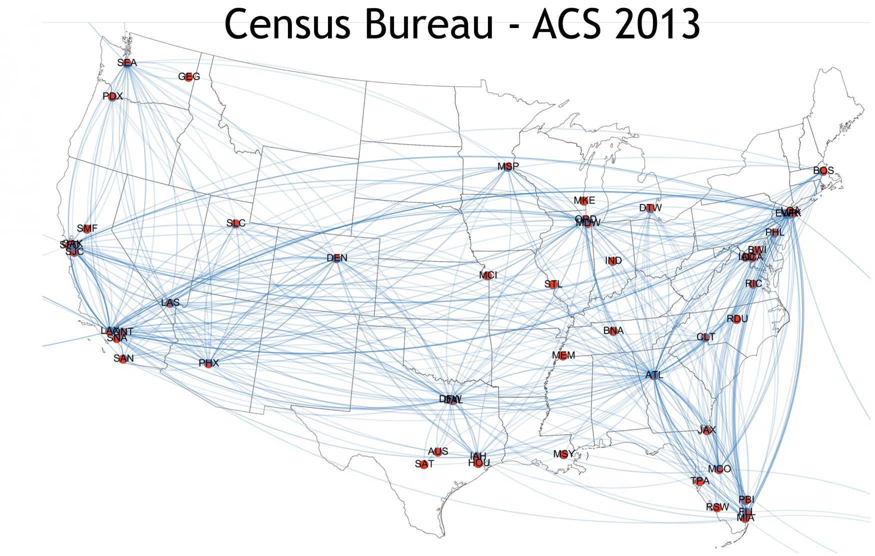
S → E → I → R

$$
\begin{aligned}
\frac{dS_i}{dt} &= = -\beta S_i(t)\frac{I_i(t)}{N_i} \\
\frac{dE_i}{dt} &= \beta S_i(t)\frac{I_i(t)}{N_i} - \alpha E_i(t) \\
\frac{dI_i}{dt} &= \alpha E_i(t) - \gamma I_i(t) \\
\frac{dR_i}{dt} &= \gamma I_i(t)
\end{aligned}
$$

National and Regional Mobility



US Commuter Data
Census Bureau - ACS 2013

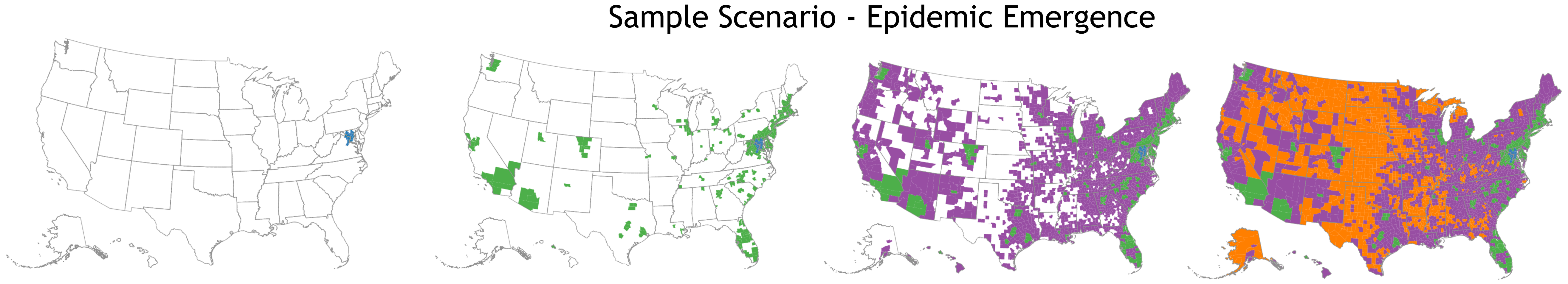


US Domestic Air Travel
Bureau of Transportation - T100 2015

Modeling the effective force of infection due to the temporal travel matrix

$$I_j^{\mathrm{eff}} = \sum_i \Theta_{ij} I_i; \;\; N_j^{\mathrm{eff}} = \sum_i \Theta_{ij} N_i$$

Sample Scenario - Epidemic Emergence



Day 30 | Day 60 | Day 90 | Day 120

Formulation

Spatiotemporal allocation of vaccines
- Space - State level (pro rata to counties)
- Time - Weekly resolution

Temporal budget constraint
- Number of vaccines available each week
- Historical data source: FluVaxView

$$
\begin{aligned}
&\underset{X}{\text{minimize}} && f(X) \\
&\text{subject to} && \sum_i X_{i,t} \leq B_t, \quad \text{for all } t.
\end{aligned}
$$

Baseline
Population proportional vaccine allocation

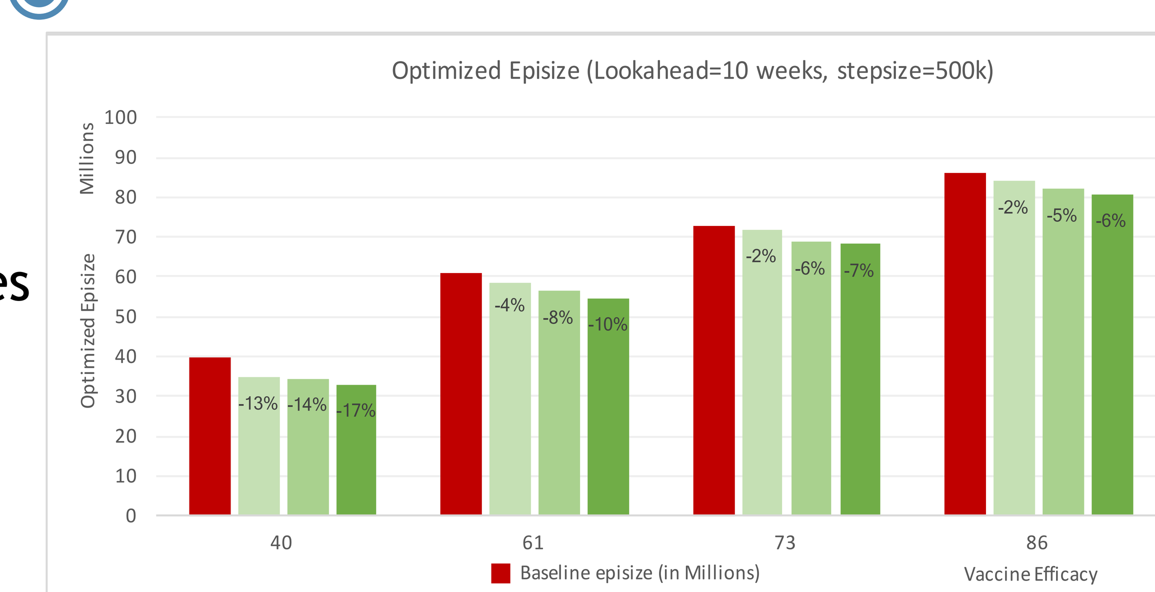
Approach
Greedy algorithm with bounded look-ahead

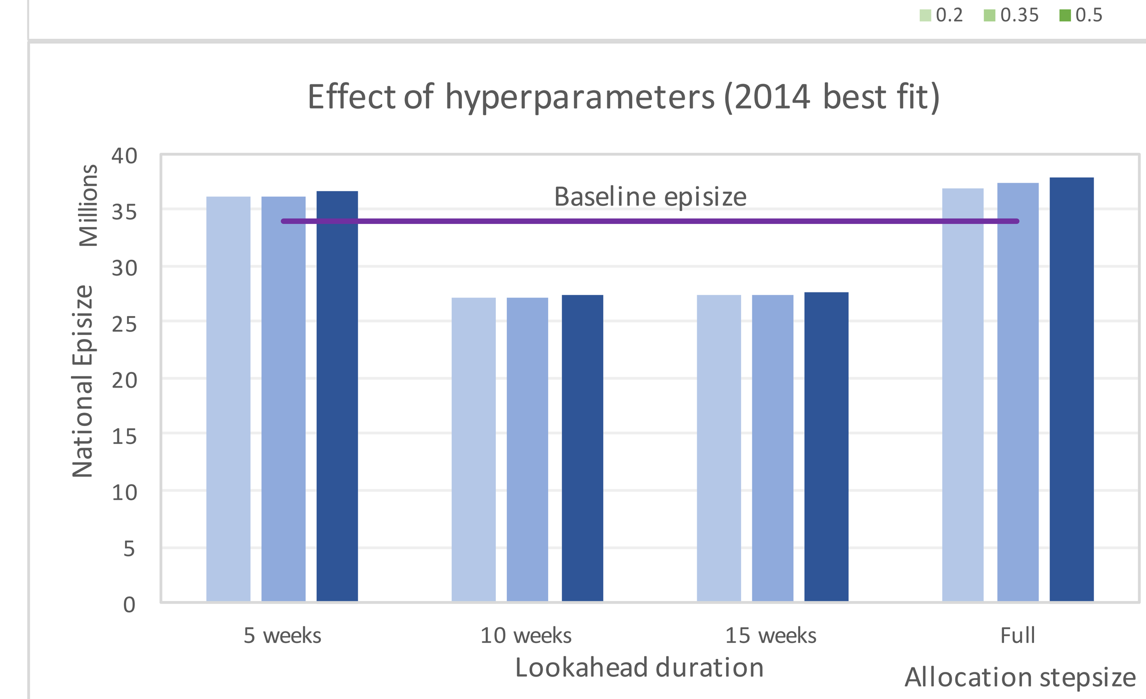
Scenarios
Four different reference attack sizes
- 40 million, 61 million, 73 million, 86 million
- Based on 2014-15, 2009-10, 1957/68 and 1918 estimates
- Achieved by tuning the transmissibility

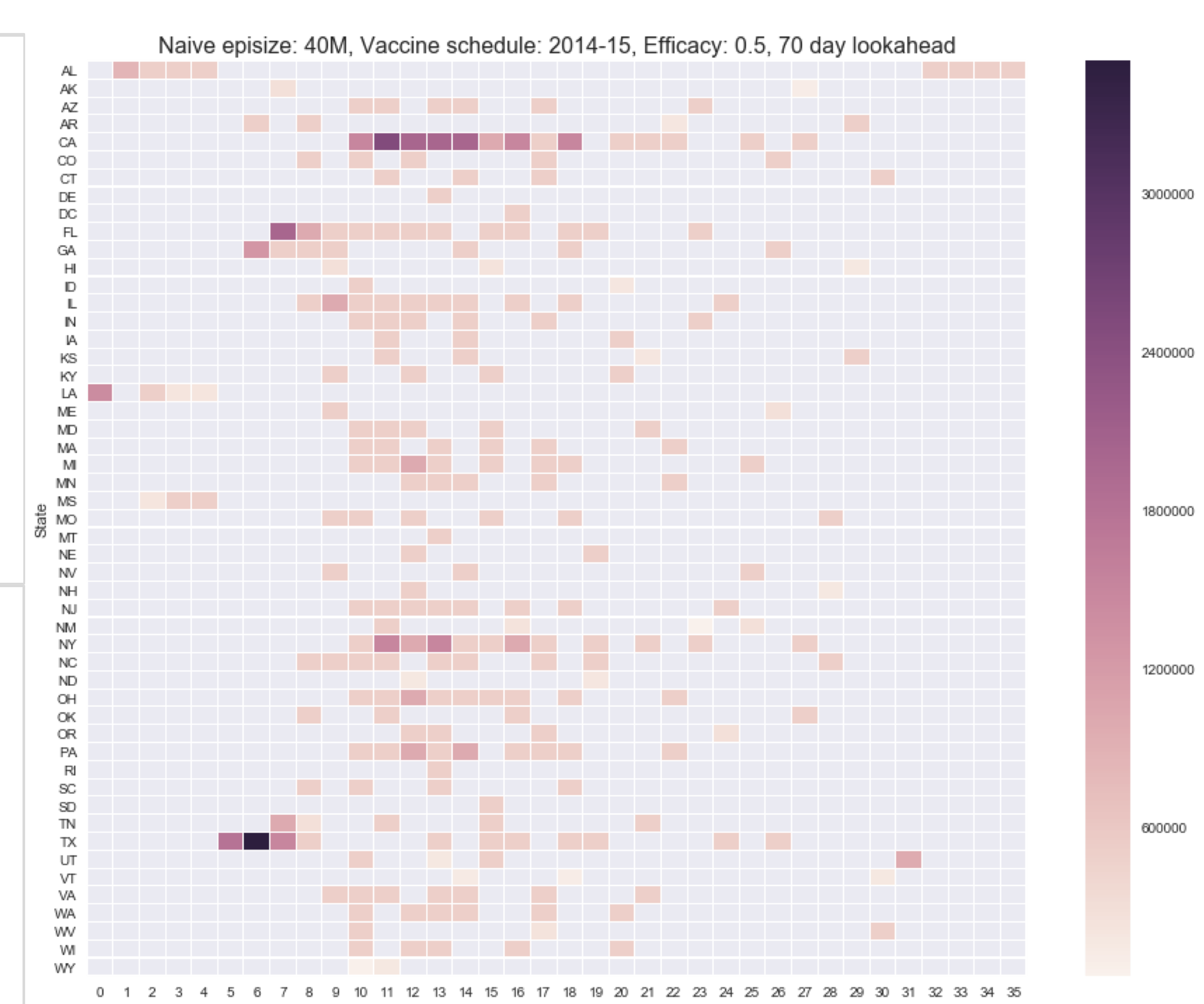
Parameter space
- Vaccine efficacy: Low (0.2), Medium (0.35), High (0.5)
- α = 0.67 (avg. incubation period = 1.5 days)
- γ = 0.4 (avg. infectious period = 2.5 days)
- Vaccine delay = 14 days
- Time - Weekly resolution

Optimization hyperparameters
- Lookahead duration: 5 weeks, 10 weeks, 15 weeks, Full
- Vaccine distribution units: 100k, 200k, 500k

Results







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