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?

Formulation

**National Influenza Spread Model**

**Simulation Framework**

- Datasets: Commuter flow, Airline flow, Patch populations, Historical influenza data, Historical vaccine data
- Travel module
- Calibration module
- Disease dynamics module
- Optimization module

**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

\[
\text{minimize} \quad f(X) \\
\text{subject to} \quad \sum_{t} X_{i,t} \leq B_t, \quad \text{for all } t,
\]

**Baseline**

Population proportional vaccine allocation

**Approach**

Greedy algorithm with bounded look-ahead

Sample Scenario - Epidemic Emergence

Day 30
Day 60
Day 90
Day 120

**National Spread Model**

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

\[
\frac{dS_i}{dt} = -\beta S_i(t) \frac{I_i(t)}{N_i} \\
\frac{dE_i}{dt} = \beta S_i(t) \frac{I_i(t)}{N_i} - \alpha E_i(t) \\
\frac{dI_i}{dt} = \alpha E_i(t) - \gamma I_i(t) \\
\frac{dR_i}{dt} = \gamma I_i(t)
\]

**National and Regional Mobility**

**Results**

- 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)
- \( \alpha = 0.67 \) (avg. incubation period = 1.5 days)
- \( \gamma = 0.4 \) (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

Flat
Baseline
Optimized Episize (look-ahead: 10 weeks, endpoint: OSN)

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**Effect of hyperparameters (2014 best fit)**

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