COVID-19 Vaccine Allocation

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Agenda

Notice how this is not bright orange.

1. Motivation
2. Our Problem
3. The Data
4. Codifying the Data
5. The model
6. AMPL Implementation
7. Results
8. Recommendations
9. Future Improvements

MOTIVATION

Current Vaccine Allocation Strategy

Federal Level

- Federal Government buys vaccines from pharmaceutical providers
- Allots them to States based population size

State Level

- Colorado has 1.69% of the US' total population
- It receives 1.69% of available doses at any given time from the Federal Government

County

- Available service provides (think: hospitals) in a county can sign up to receive doses
- Doses provided are based on capacity, population, and committee recommendations

Motivation

- Committee recommendations can be inherently biased

- Population Density is only one thing that should be considered

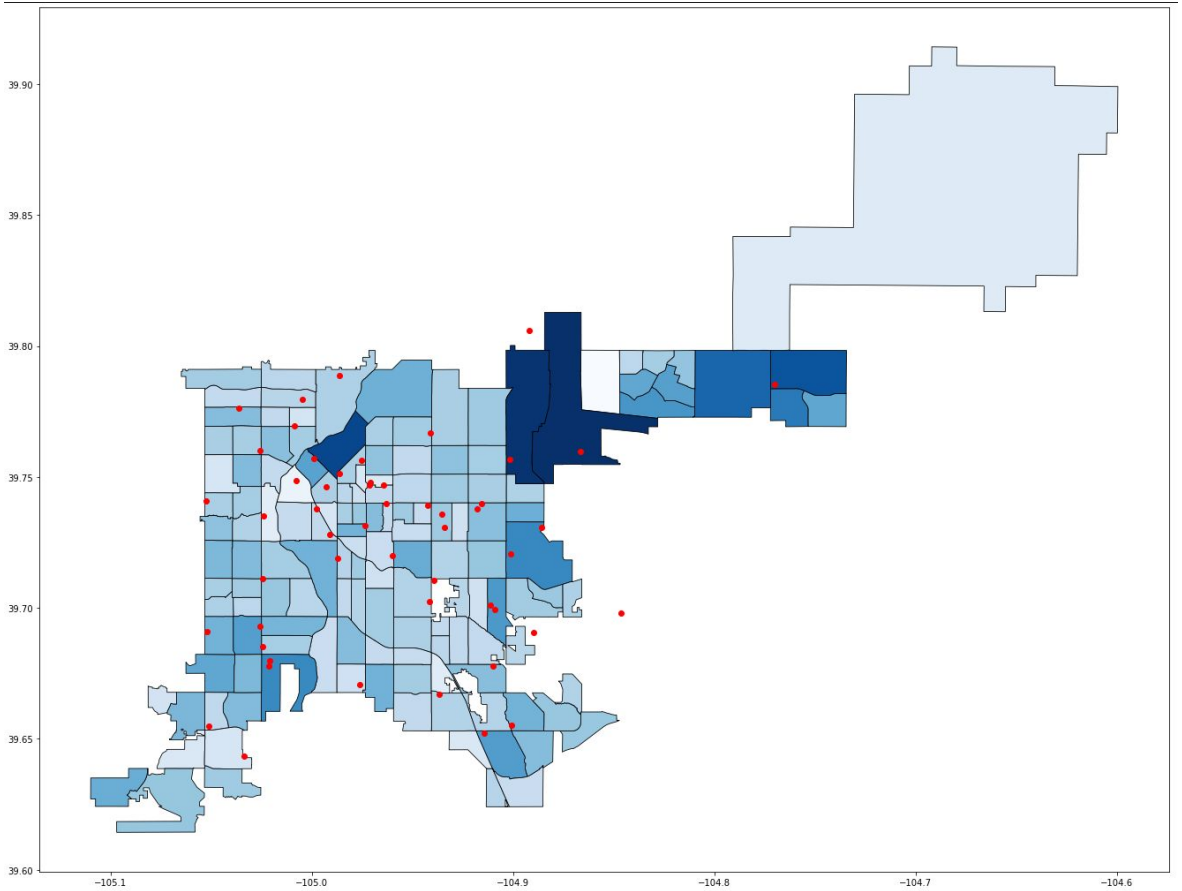
Our Proposal

- Optimize vaccine allocation in a way that minimizes human cost
- Consider the cost of *not* vaccinating people in a census tract

THE DATA

General Data

- Allocation limited to the 144 census tracts for Denver County
- 52 Vaccine Service Providers
  - Pharmacies
  - Clinics & Hospitals
  - Mass Vaccination Sites
- Cost to open a Service Provider
- Maximum Vaccine capacity at provider
- Distance from census tract centroids to all service providers

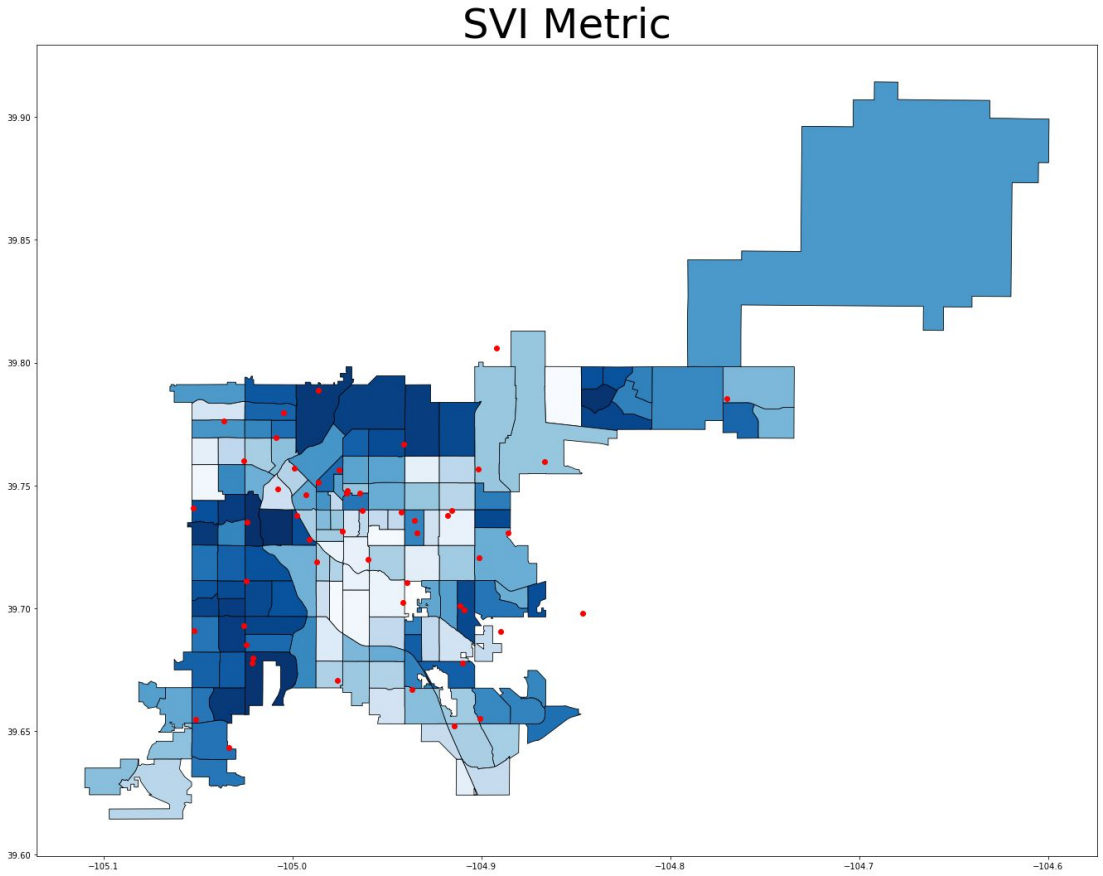


Total Population Density overlaid with vaccine providers

Cost of not vaccinating

- Social Vulnerability Index of the CDC, which is derived from several factors:
    - Socioeconomic Status
    - Household Composition & Disability
    - Minority Status & Language
    - Housing Type & Transportation

    - In 2018, two additional variables were added
        - ACS Estimates for persons without health insurance
        - Estimates of daytime population



SVI overlaid with vaccine providers

CODIFYING THE DATA

Balancing costs

- Human “cost” of not vaccinating is a very complex issue.

- Choose to make the cost of not vaccinating equal to population with a few modifications:
    - SVI added based on area in which they live
    - Reduced depending on vaccination rates in their community
        - Multiply by 0.70 - %vaccinated

- “Cost” to obtain Vaccine based on longest distance reasonable to travel to obtain vaccine (about 25 miles)
    - A longer distance also lowers likelihood of getting even if available

PROBLEM FORMULATION

Initial Considerations

- Point in time
  - Winter 2020
- Number of Vaccines
  - 10% of the County

Objective Function

$$\min \quad \sum_i \sum_j (d_{ij} - \frac{c_i}{2p_i}) x_{ij}$$

$p_i = \text{population}$

$d_{ij} = \text{cost of vaccine } i \text{ from } j$

$c_i = \text{cost of vaccinating no one in } i$

- Cost of vaccine based on distance in latitude and longitude
- The one-half is based on an average maximal distance away a vaccine can be assigned, in this case it is roughly equivalent to 25 miles.

Constraints

$$
\begin{array}{lllll}
\text{s.t.} & \sum_j x_{ij} & \leq & 0.7p_i - v_i & x_{ij} \text{ (int var)} = \text{vaccines from } j \text{ to } i \\
 & & & & v_i = \text{vaccinated individuals} \\
 & x_{ij} & \geq & 0 & p_i = \text{population} \\
 & \sum_{ij} x_{ij} & \leq & S & S = \text{Supply} \\
 & \sum_j x_{ij} & \geq & b_i \geq 0 & b_i = \text{equity} \\
 & f_j m_j y_j & \leq & \sum_i x_{ij} \leq m_j y_j & m_j = \text{max capacity} \\
 & & & & f_j = \text{min open ratio} \\
 & & & & y_j \text{ (bin var)} = 1 \text{ if } j \text{ open}
\end{array}
$$

IMPLEMENTATION

Implementation - Interesting Observations

8113 Parameters, 7488 Variables, 7827 Constraints

- Natural Relaxation
  - MINOS 74 iterations
  - CPLEX 1 dual simplex iteration (0 in Phase I)

- Y Binary (52 variables)
  - MINOS 264 Iterations, ignores binary but bounds between 0 and 1
  - CPLEX 66 MIP Simplex Iterations, 0 Branch-and-Bound Nodes

- Y Binary (52 variables) and X Integer (7,436)
  - MINOS 181 Iterations, ignores binary and integrality but bounds y between 0 and 1
  - CPLEX 66 MIP Simplex Iterations, 0 Branch-and-Bound Nodes

- We were under the impression that CPLEX would brand-and-bound on integer variables

Implementation - Decreasing Value with Increasing Vaccines - Possible Solutions

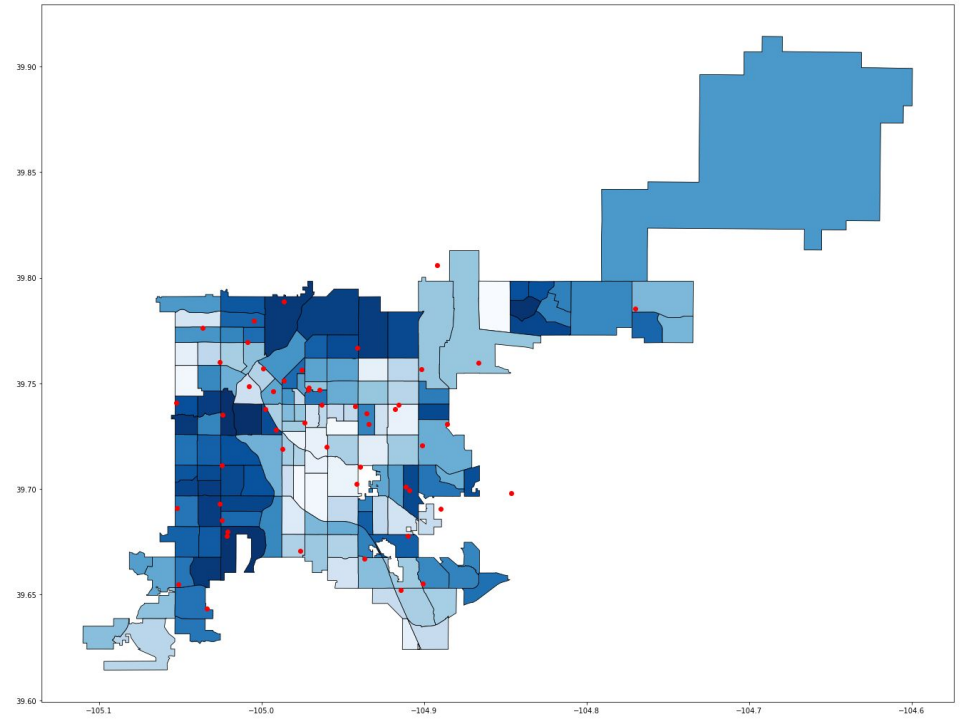
- Quadratic Programming

- Iterative Process

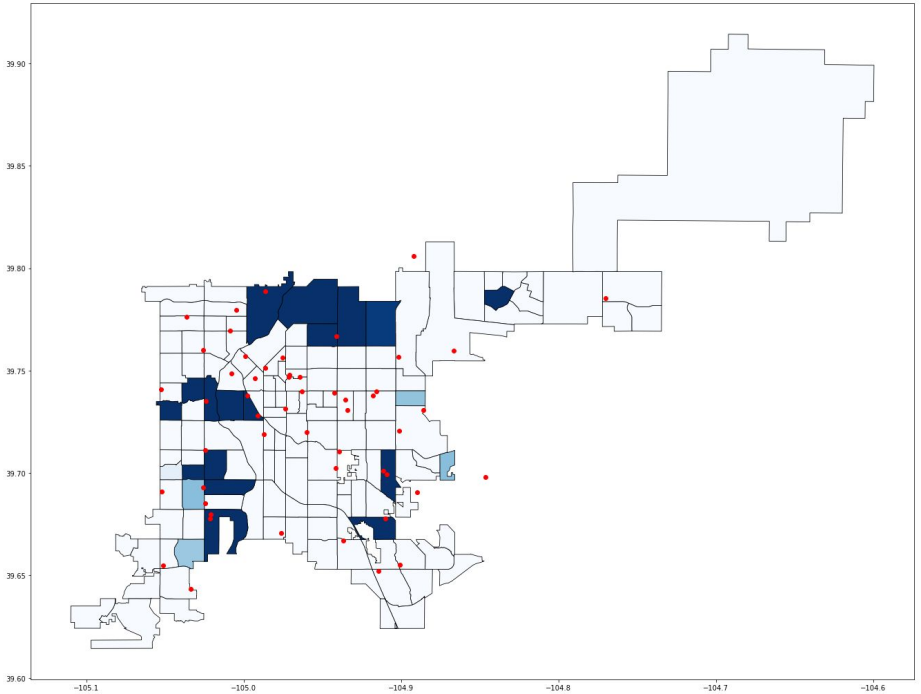
RESULTS

Our Results

SVI Metric

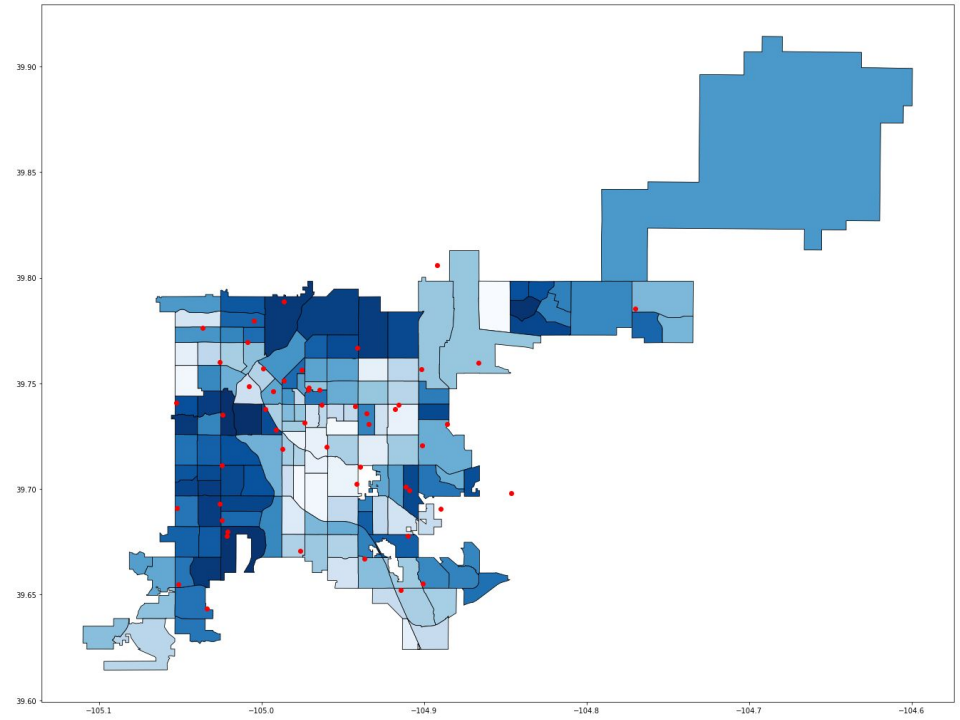


One batch distribution

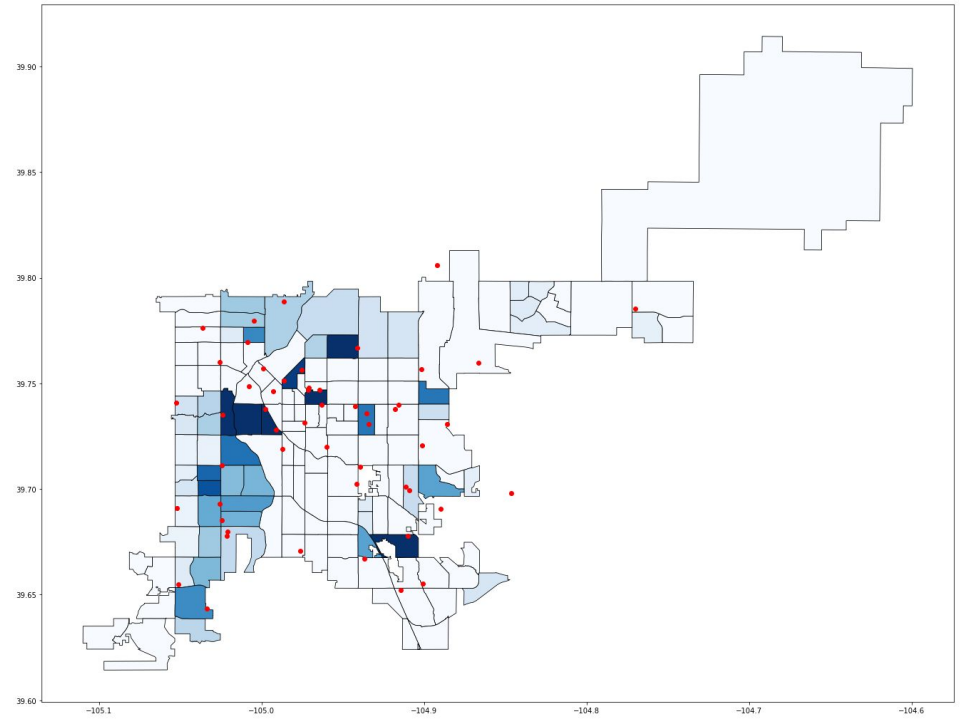


Our Results

SVI Metric



Multi-batch distribution



RECOMMENDATIONS

Recommendations

- Vaccine allocation should take into consideration under-represented or vulnerable communities to ensure herd immunity

- Any vaccine allocation strategy should take into account the complexities of the human capital “cost” of distribution

- During initial vaccine distribution, we recommend a concentrated allocation strategy
    - Pick high vulnerability communities first

Future Work

- Equity Data
- Non-Linearity
- Times later than zero

References and Data

- American Community Survey Tracts
  - https://www.denvergov.org/opendata/dataset/city-and-county-of-denver-american-community-survey-tracts-2015-2019
- Service Providers and Capacities
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- CDC Social Vulnerability Index
  - https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/SVI_documentation_2018.html

Thank you