Multi-Objective Optimization of Healthcare Facility Access Equity and Efficiency Using a CVaR-Based Model

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Introduction

- Healthcare facility allocation must balance population density, distance, and subgroup fairness.
- Constructed an MILP which optimizes clinic allocation subject to a convex combination of the twin objectives:
  - minimizing weighted average clinic distance,
  - optimizing a fairness metric based on Conditional Value at Risk (CVaR).

Methods

- Problem Definition
  - A tract is *disadvantaged* iff its centroid lies in a Medically Underserved Area/Population per HRSA.
  - Each tract centroid is a candidate site.
- $$\min_{x,\gamma,z} \lambda \frac{\sum_{i\in\mathcal{T}} w_i \sum_{j\in\mathcal{C}} d_{ij}x_{ij}}{\sum_{i\in\mathcal{T}} w_i} + (1-\lambda)\left(\gamma + \frac{1}{2(1-\alpha)}\left(\frac{1}{t_{dis}}\sum_{i\in\mathcal{T}_{dis}} z_i + \frac{1}{t_{adv}}\sum_{i\in\mathcal{T}_{adv}} z_i\right)\right)$$

subject to:

$$\sum_{j\in\mathcal{C}} x_{ij} = 1, \quad \forall i \in \mathcal{T}$$

$$x_{ij} < y_j, \quad \forall i \in \mathcal{T}, \forall j \in \mathcal{C}_{cand}$$

$$y_j = 1, \quad \text{if } j \in \mathcal{C}_{exist}$$

$$\sum_{j\in\mathcal{C}_{cand}} y_j = p, \quad z_i \geq \sum_{j\in\mathcal{C}} d_{ij}x_{ij} - \gamma, \forall i \in \mathcal{T}$$

$$z_i \geq 0,\ \gamma \in \mathbb{R},\ x_{ij} \in \{0,1\}\, \forall i \in \mathcal{T}, j \in \mathcal{C}, y_j \in \{0,1\}\, \forall j \in \mathcal{C}_{cand},$$

where $\alpha \in (0,1)$ = confidence level; $\mathcal{T}$ = tracts; $\mathcal{C}_{cand}$ = candidate sites; $\mathcal{C}_{exist}$ = existing sites; w_i = population in tract i; d_{ij} = distance from tract i to clinic j; $\mathcal{T}_{dis}$, $\mathcal{T}_{adv}$ = two subgroups; $t_{dis} = |\mathcal{T}_{dis}|$, $t_{adv} = |\mathcal{T}_{adv}|$; p = number of new clinics; $x_{ij} \in \{0,1\}$ = tract i assigned to clinic j; $y_j \in \{0,1\}$ indicates whether candidate j is chosen.

Future Work

- Extend to regions with different geographic aspects.
- Compare with models using alternative fairness notions.

Experiments and Results

- Data Preparation
  - Study scope: *Philly Metro Area.*
  - Sources: census.gov, ACS 5-year data, HRSA.
- Ran experiments for different tradeoff parameters $\lambda \in [0,1]$, $p = 5,\ 10,\ 15$, and $\alpha = 0.95$.
- Larger $p \rightarrow$ lower weighted distance. For all p, sharper decrease around $\lambda = 0.6$.
- For small λ, increasing λ can **improve average distance without impacting the fairness metric**.
- Mild tradeoff between fairness and distance.
- Allocation results for $p = 10$ with $\alpha = 0.95$ and $\lambda = 0.8$ (bottom) and $\lambda = 0.0$ (top).
- Similar allocation results but different fairness value: 16.387094 versus 16.526801.