Problem: Limited Healthcare Access in Malawi

Malawi is an African nation facing a serious shortage of health care providers, with only 1.9 physicians/100,000 people compared to 267 physicians/100,000 people in the U.S.28 To address this crisis, Malawi is scaling up its nationwide program of community health workers, or Health Surveillance Assistants (HSAs). Beyond Traditional Borders has developed a Health Surveillance Assistant Backpack to supply these HSAs. To improve the effectiveness of these programs, we aim to optimally

- Place HSAs across Malawi with a target ratio of 1 HSA to 1000 people
- Assign backpacks to HSAs and estimate the number of packs required
- Choose resupply centers from existing hospitals and health centers

Solution: Integer Program Resource Optimization

We used the p-median problem to assign backpacks and resupply centers:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} + \sum_{i=1}^{m} f_{i} y_{i}$$

where:
- $\xi_{ij}$ whether HSA $j$ serves EA $i$
- $W_{ij}$ is the weighted distance
- $x_{ij}$ is variable cost and $f_{i}$ is fixed cost

We applied these models by processing Malawi 1998 census files in ArcGIS and writing a C++ routine to interface with Gurobi, a solver for large-scale mixed integer optimization problems.

Parameters

- Node weights depend on population, health center location, and population density
- Edge weight is distance between EA and its HSA
- $W_{ij} = \text{node weight} \times \text{edge weight}$

Results

- Number of variables: reduced from 74 million to 23 million
- Runtime: 4.5 hours
- Within 0.0043% of optimal
- Mean distance between HSA and the EA served = 0.45 km, median = 0 km, max = 15.2 km
- Mean number EAs an HSA serves is 1.41, median = 1, max = 23

Parameters

- Backpack fixed cost = $362.91
- Variable cost depends on distances between backpacks and HSAs
- Backpack capacity = 3 HSA pairs

Results

- Number of variables: reduced from 60 million to 10 million
- Runtime: 2 hours
- Within 1.87% of optimal
- Number backpacks chosen = 2220
- Total cost = $805,660
- 93% of backpacks at full capacity

Parameters

- Resupply center fixed cost = $0
- Variable cost = distance between backpack and resupply center
- Hospital capacity = 80 backpacks; health center capacity = 10 (Case 1, reliable supply chain) or 0 (Case 2, unreliable)

Results

- Number of variables: 108,780
- Runtime: under 10 seconds
- Within 0.0001% of optimal
- Case 1: 623/710 facilities used.
  - Mean number packs resupplied = 4, $max = 14, min = 1$
- Case 2: 49/49 hospitals used.
  - Mean number backpacks resupplied = 45, $max = 80, min = 10$

Impact

- If deployed optimally, HSAs and HSA backpacks could significantly improve the Malawian people’s healthcare access
- Providing enough backpacks to cover the country of Malawi may be prohibitively expensive even if they are allocated optimally
- The large scope of our analysis pushed the limits of Gurobi, a high-performance optimization software package

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