JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Modeling Demand for Medical Resources

OSG All Hands Meeting 2021—March 1, 2021

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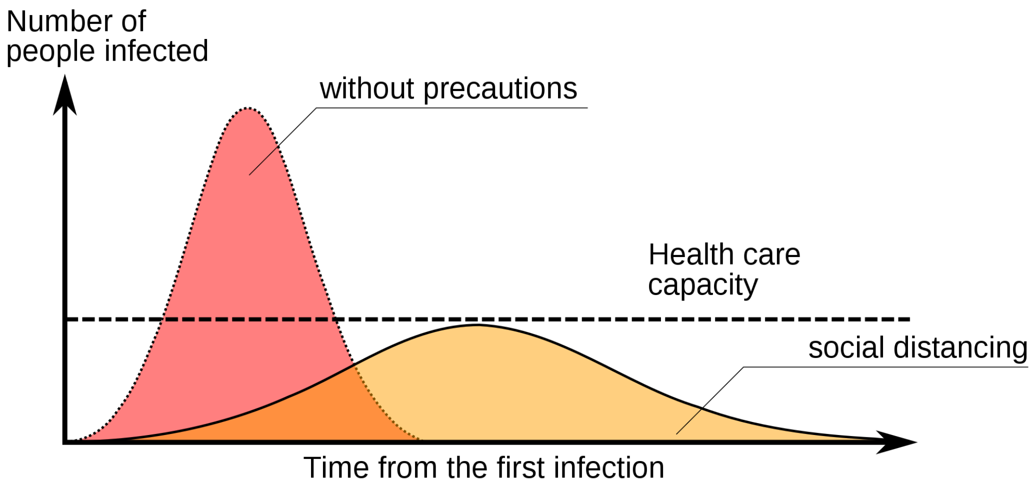
Flattening the Curve

Protect the Resources to Protect Us All

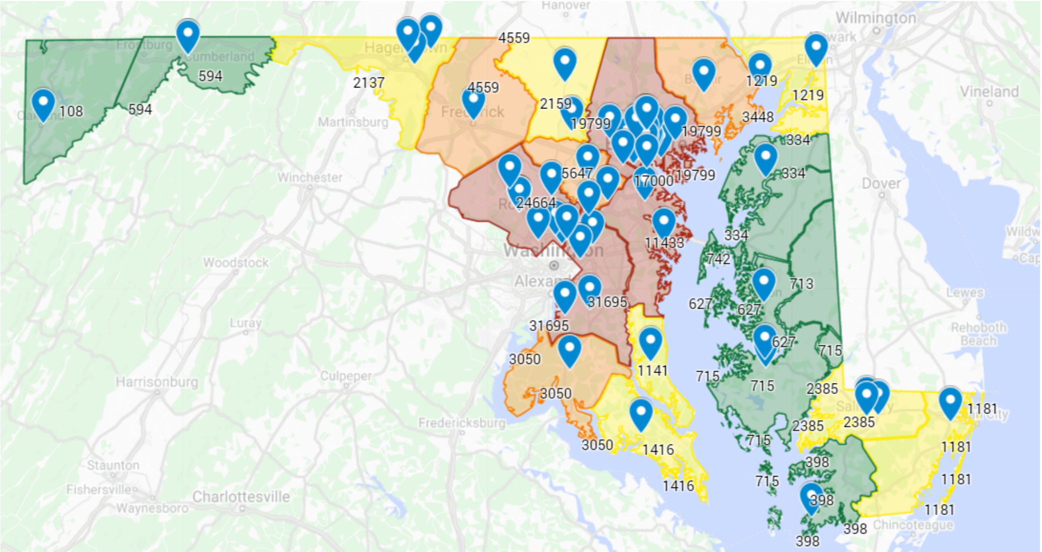
- China and Italy were the two hardest hit countries at the beginning of COVID-19
  - Both implemented early lockdowns
- Italy was running out of hospital beds and ventilators
  - Hospitals reported new arrivals every 5 minutes



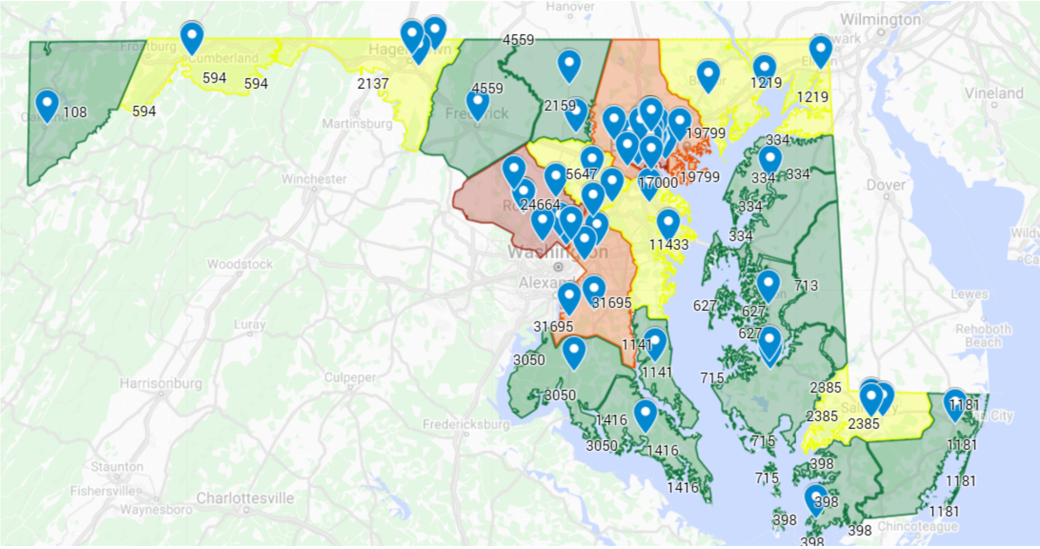
By Johannes Kalliauer via Wikimedia Commons

Flattening the curve protects resources, but the allocation still has to work

COVID-19 in Maryland



Counties in Maryland by Incidence of COVID-19



Counties in Maryland by Number of Hospitals

Prior Public Health Optimization Work

- Resource Allocation
  - American Hospital Capacity and Projected Need for COVID-19 Care
  - Allocation of Intensive Care Unit Beds in Periods of High Demand
  - COVID-19 Capacity Analysis Tool for Hospitals and EDs
- Simulation
  - How Simulation Modelling Can Help Reduce the Impact of COVID-19
  - A Nonhomogeneous Agent-Based Simulation Approach to Modeling the Spread of Disease in a Pandemic Outbreak
  - Locally Informed Simulation to Predict Hospital Capacity Needs During the COVID-19 Pandemic

The Question

Can we prevent resource shortages from affecting our ability to treat patients?

Patient Allocation Model

- Goals
  - Maximize utilization of hospital beds
  - Minimize patient travel
  - Minimize displacement of future patients
- Decisions
  - What hospital do we send a patient to?
  - What penalty do we incur for potentially displacing patients?
- Implementation
  - Python and Pyomo
  - Solvable with CBC, CPLEX, GLPK

$$\min \sum_{j} d_j x_j + \sum_{j,t} p_{jt}$$

$$\text{s.t.} \sum_{j} x_j = 1 \ \forall j$$

$$x_j \leq b_j x_j - o_j x_j - \sum_{t' \leq t} a_{jt'} x_j + \sum_{t' \leq t} d_{jt'} x_j + p_{jt} \ \forall j, t$$

$$x_j \in \{0,1\}$$

$$p_{jt} \geq 0$$

Simulating the Epidemic

- Hospital
  - Each hospital in Maryland with ICU beds
  - Count of ICU beds associated
- Population
  - Population taken at level of census tract
- Two hospital assignment policies:
  - Go to closest hospital
  - Allow LP to solve for “best” hospital
- Implementation
  - Discrete event simulation (DES)
  - Used Python and SimPy
- Hospitals are key resource in simulation
  - Time in ICU Weibull scaled by user parameter
- Patients generated at random intervals
  - Time interval exponential with user parameter
  - Tract selection weighted by population
- Metrics:
  - Distance Travelled
  - Number of Patients Displaced
  - Wait Time

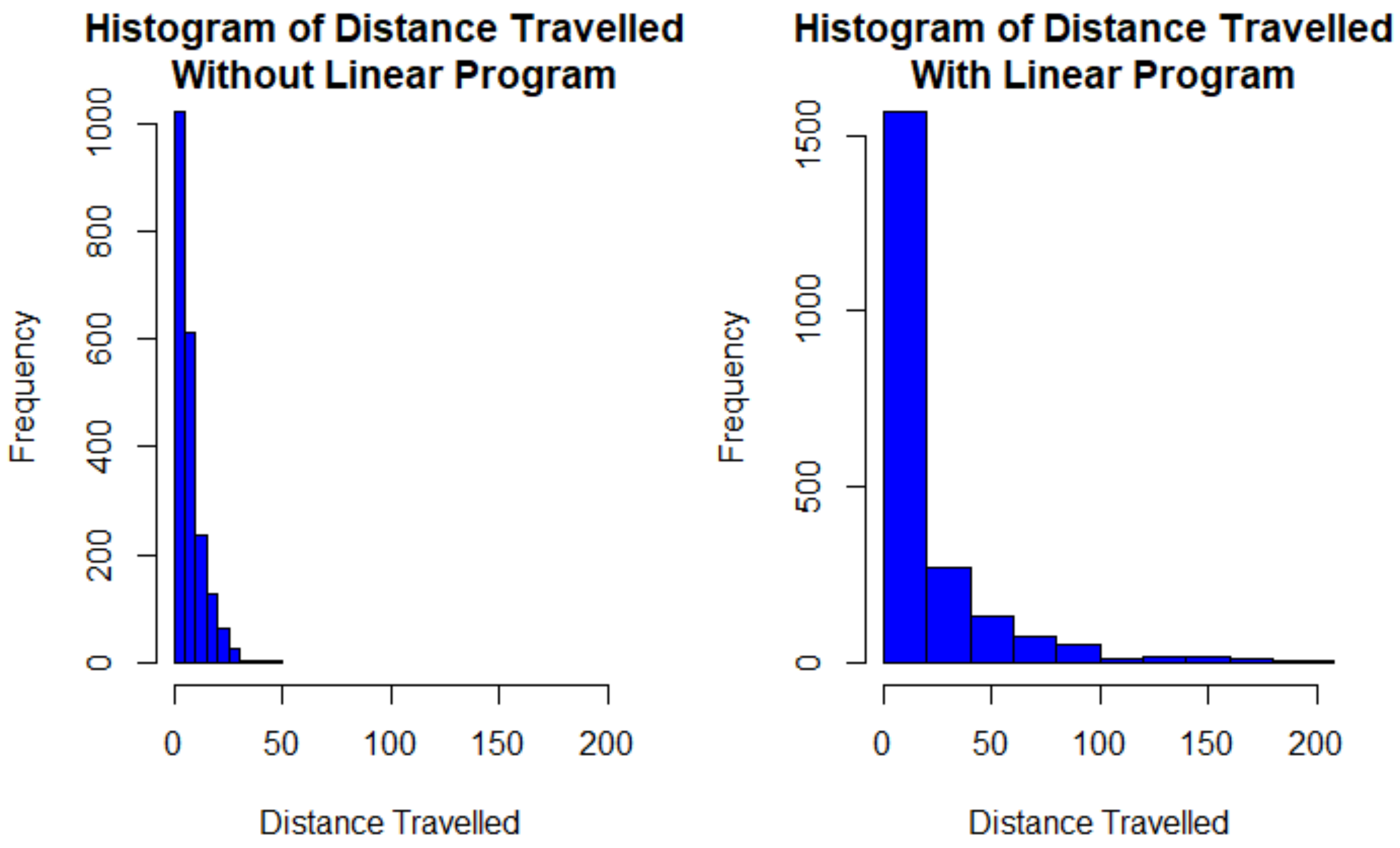
Goal is to evaluate policies against each other

How OSG Helped

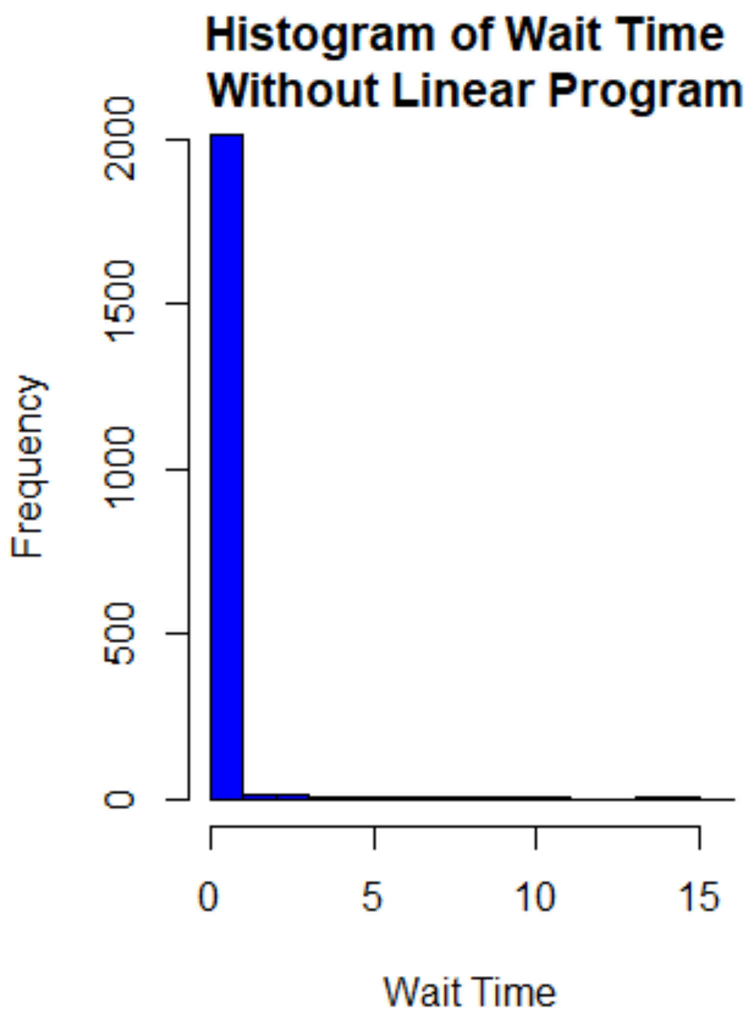
- Monte Carlo simulation
  - Requires many runs
  - All runs are independent of each other
  - Perfect HTC problem
  - OSG made for HTC
- 1600 runs for each policy made
  - Run may take multiple hours
  - Just need to capture metrics

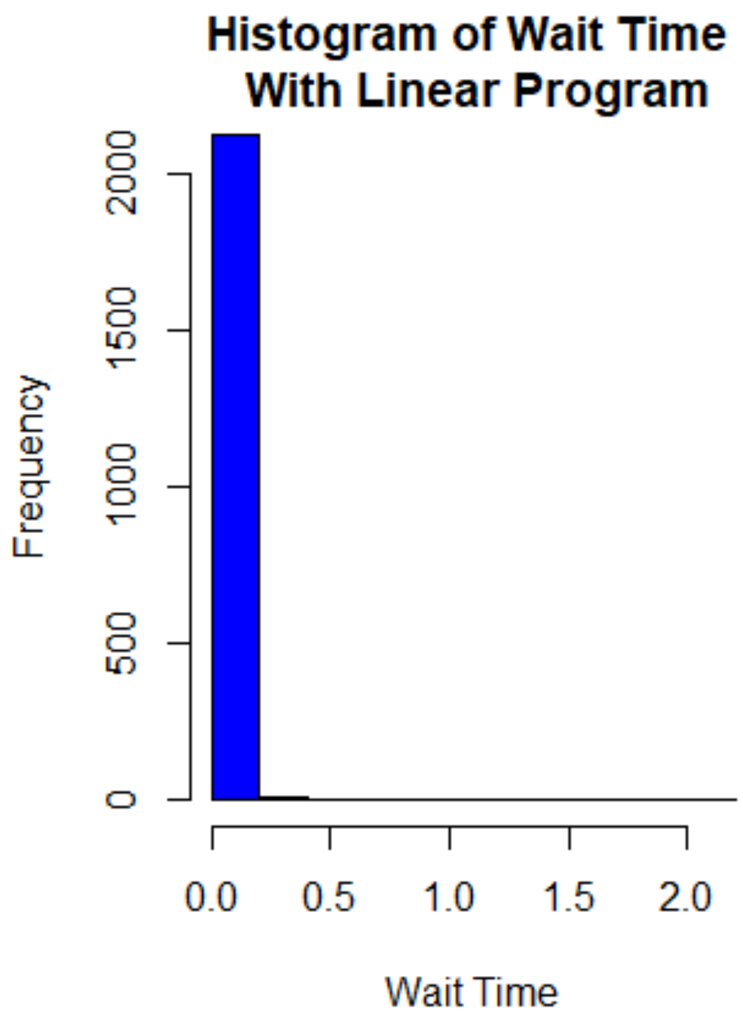
- Python worked well
  - Used virtualenv per OSG documentation
  - All required packages added to the venv
  - Added compiled copy of glpk to venv
    - Felt shady but necessary for Pyomo
  - CSV files with patient stats written
  - Logfiles via spdlog generated
  - Results turned to OSG submit node
    - Processed stats in R
    - Logs provided info to answer questions

Distance Travelled

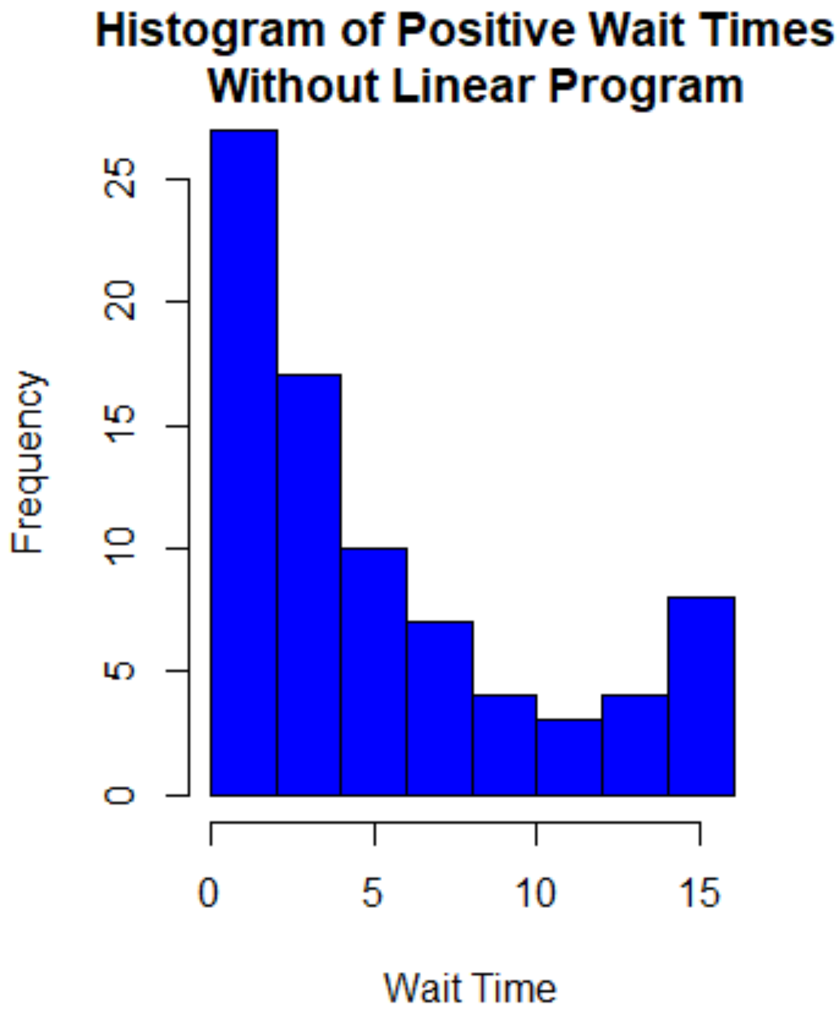


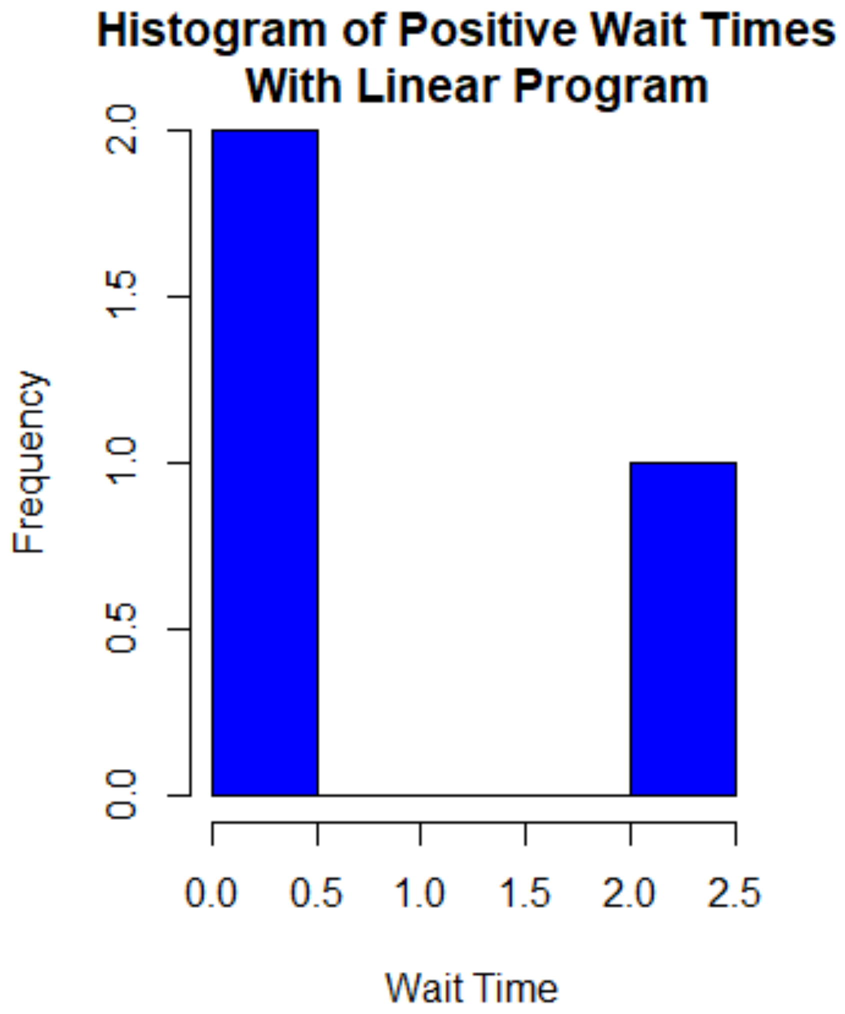
Waiting Time





Positive Wait Times





Limitations and Future Directions

- Simulation Model
  - Fine tune parameters to generate patients more accurately
  - Working to acquire patient data to generate patients in simulation as actual COVID-19 epidemic
- Determine coefficients for the objective function
  - Distance to the nearest hospital is weighted the same as the penalty
  - We assume that the penalty is the same for each day
  - Adjust the coefficient function to more accurately represent the tradeoff between waiting and travelling
- Policies
  - Send patients to the closest hospital with an open bed
- Metrics
  - Bed Utilization

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