Proposition to Optimize Fire Stations for Wildfires

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Introduction

The rising trend in wildfire occurrence and severity has put a strain on wildfire management organizations by spreading out limited resources to meet increasing demand. There has been extensive prior research and data collection to determine the areas of highest risk and to predict regional wildfire damages based on historical trends.

Our group aims to utilize this data to best determine fire station placement, optimizing where resources are allocated to reduce the time and investment needed to effectively mitigate wildfires. Using existing research, we are able to calculate optimal fire station locations by utilizing a **single-objective facility location** problem algorithm incentivized for cost reduction.

Methodology – Data Collection

- Land data was gathered from Data Basin by converting images into forest density and fire hazard severity matrixes.
- Forest density data was used to decide potential locations of stations and fires.
- Each cell was classified as either unforested land (A), OR a light, medium, heavy, or very heavy forest (B).
- Each cell A was considered a potential fire station location and each cell B was considered a potential fire occurrence.
- The demand for each fire was calculated as a combination of its density and its hazard severity.

Methodology – ILP setup

- **Objective Function: (total cost)**

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} d_j t_{ij} y_{ij} + \sum_{i=1}^{N} f_i x_i$$

Variables to be computed by model

Where:
N = number of (optimal) fire stations,
M = number of possible forest fires,
x_i = binary variable denoting a station (1=yes, 0=no)
y_{ij} = the fraction of the total demand d_j of fire j that station i has satisfied
t_{ij} = and the transportation cost between station i and customer j
f_i = associated cost of building & maintaining a new fire station

Methodology – ILP Constraints

$$\boxed{s.t. \ \sum_{i=1}^{N} y_{ij} = 1 \ \ \forall j \in \{1, \ldots, M\}}$$

each fire's demand has to be met by some combination of stations' resources

$$\boxed{\sum_{j=1}^{M} d_j y_{ij} \leq k_i x_i \ \ \forall i \in \{1, \ldots, N\}}$$

the capacity of each station has to exceed total demand of all forest fires on that station

$$\boxed{x_i \in \{0, 1\} \ \ \forall i \in \{1, \ldots, N\}}$$

there has to be an integer number of stations

Methodology – Sensitivity Analysis

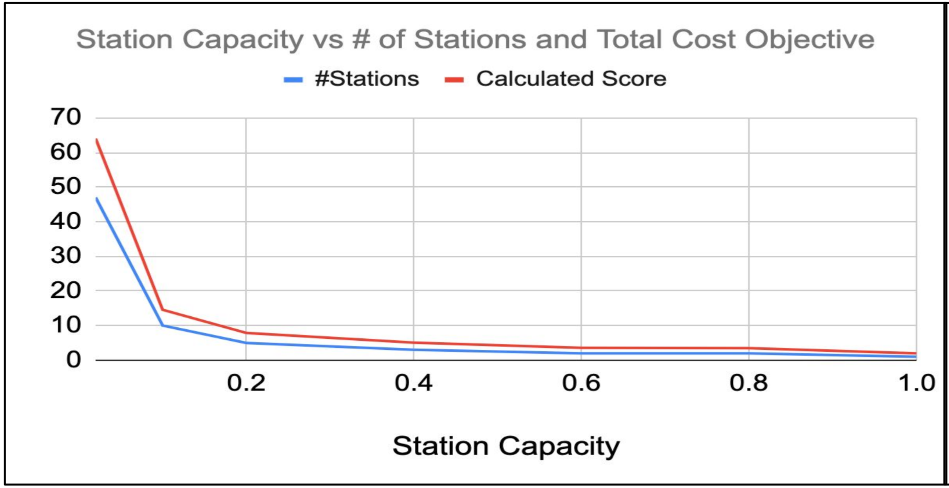
We can vary:

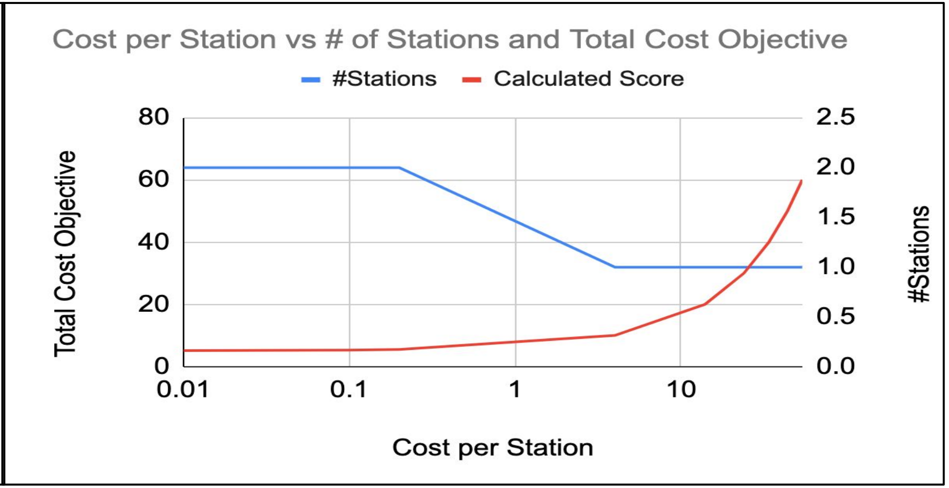
- the capacity of each station
- the cost of building & maintaining a station
- the transportation cost from stations to fires
- the demands (probabilities of fire) based on forest density and severity

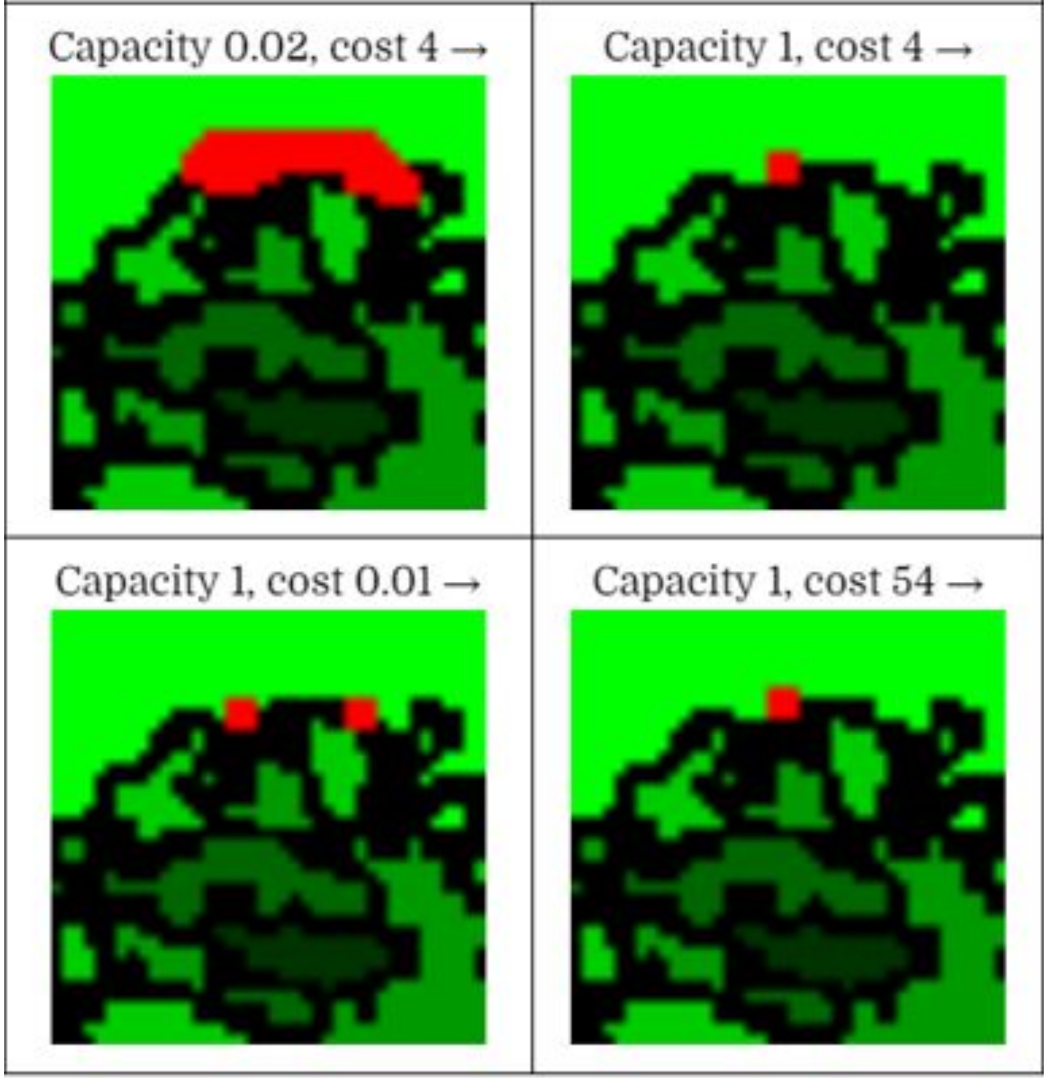
And view its effect on:

- # of stations placed
- total transportation cost (objective function)

Methodology - Sensitivity Analysis Cont.







The extreme cases for both varied parameters (capacity and cost) are shown.

Notes: Red cells represent fire stations placements outputted by the model. The darker green the cell, the denser the forest. Black cells are boundaries between densities.

Further Work

While our project was largely a proof-of-concept, we can see our linear programming model being improved in the following ways:

- The model can be adapted to support multiple types of fire stations
- It can be repurposed to minimize the maximum distance or transportation cost between a station and a fire
- Additional data can be factored in such as proximity to water sources, access to highways, and fire prioritization based on burn rate/potential damages
- Improve cost estimates of transportation and construction costs
- Create custom FLP solver or use MATLAB Optimization Toolbox rather than Python CVXPY library

Applications

Although our model in its current form will need refinement to be more practical for determining fire station placements, it can still be used to evaluate existing fire station locations and allow for redistribution of fire fighting assets to critical stations and regions. The same model could also be readily modified to apply to urban areas rather than wildfires.

Additional Research - Topics

- What kinds of support do fire stations typically provide to wildfires
- How is it currently decided where firefighting aircraft will be home based?
- Approximate maintenance and operation costs for firefighting aircraft?
- How is it currently decided what resources are allocated to a given fire? (size, location, etc.)
- Are there ever shortages of resources/aircraft when fighting fires? Why does this occur?
- What are the pros and cons of using UAS in wildfire fighting operations

Additional Research - Relevance

Having this additional information would be useful if we were to develop our idea further. At one point, we considered focusing solely on where aircraft resources were positioned. Knowing more about how wildfire fighting aircraft are positioned and utilized would help us shift our project in that direction.

Answering these questions would also allow us to analyze existing resource placement strategies and account for additional details which we may have overlooked. This would help us fine tune our model to better suit the real world.

Cost Analysis

- Direct Materials Costs
  - Acquiring or manufacturing garage doors (typically made with aluminum or steel)
  - Necessary materials for building’s foundation (brick) - cost per square or cubic unit
  - Cost of landing pad materials (concrete slabs sold by square foot)
- Direct Labor Costs
  - Wages of construction workers
  - Different tasks and roles might imply different worker wages
  - Consider number of workers and hours needed to complete each task
- Overhead (indirect) Costs
  - Acquiring fire trucks, helicopters, and other vehicles from suppliers and dealers
  - Supervisor of construction operations
  - Rent, Utilities, Electric, Water
  - Wages of response unit staff members

Fire Station 61 - Buena Park

- 1.25 acres, single story
- Fire apparatus bays (3x), sleep rooms, kitchen/dining room, workout facility
- Costs (design, claiming of land, construction, demolition of old station) = $13M
- About $9.4M for station construction

Fire Station 2 - Carlsbad

- Station to be fully built and operational by Fall 2022
- Reasons for Redesign: insufficient storage capacity for vital equipment (hoses, fireproof clothing, medical)
- New station will add 7000 square feet to former station's size
- Can house up to five response vehicles
- Can store up to date equipment
- Unique features include:
    - Heating, cooling, electric systems that are energy-efficient
    - Solar panels on rooftops, solar hot water heater
    - EV chargers available for public
    - Much more (click link above)
- Costs not mentioned, but modern features and benefits suggest higher costs than other design plans

Key Considerations

- 3-5 garages for firefighting and medical transportation
- Land that is clear of barriers, such as houses, trees, rocks, other terrain
- Zoning and Permit approval from local counties (Santa Clara)
- Quick Response team consisting of firefighting crews and medical dispatch

Landing Pad - Dust Suppressants

- As dust spreads, it can cause damage to both a helicopter and certain means of fire equipment
- Use dust suppressants in areas with more risk to dust spreading
- Use concrete to create landing pad
- Second Layer options - asphalt for pavement foundation, vegetation-based cover (sod)

Current Dust-Reduction Products

- Water
  - Benefits: free to use; easily accessible - especially in a fire
  - Concerns: excess use can result in erosion/runoff (ineffective); areas with higher temperatures more vulnerable to evaporation
- Poly Binder
  - Benefit: Actively being utilized by Forest Service
  - Concerns: higher costs; product-based factors (mentioned below)
    - Implementing products might be more difficult in occupied landing areas
    - Poly Binder availability

Dimensional Recommendations

- Area should be clear of any potential obstructions (i.e. vehicles, trees, electrical)
- Touchdown pads are square-shaped (225, 400, 900 sq. units) based on helicopter size
- Ideal to determine a department or county's anticipated helicopter size prior to developing the pad's foundation
- Additional circular outer layer for safety precautions - diameter changes in proportion to helicopter and pad size

Average Cost of Concrete

- Estimated Average Cost of a Concrete Slab: $6/sq. Foot
  - Based on observations from prices from several different Google searches
  - Observed anywhere from $4-8 per unit rates
  - Anticipate higher costs in state of CA - state tends to have higher material and labor costs
- Apply pad dimensions and any additional fixed costs to estimate total costs of pad construction

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We’d also like to thank Dr. Parimal Kopardekar, Christine Clark, and the California Wildfire Community for helping guide us through this project