# Applying Linear Programming to Optimize Fire Station Location

Sharad Parulekar*, Ashish Bhave*, Matt Cady*, Samuel Kenyon*, Akarsh Tripathi*,
Dr. Parimal Kopardekar**

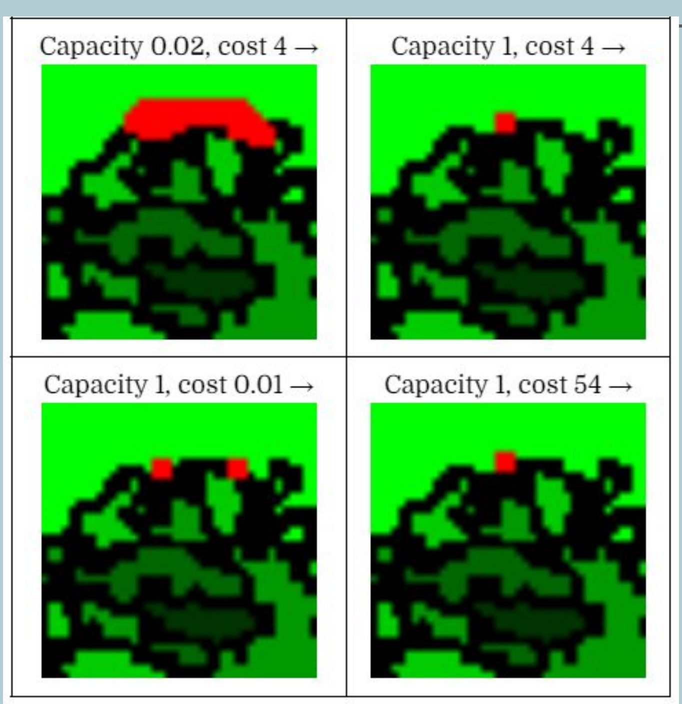
*Universities Space Research Association **NASA Aeronautics Research Institute

## 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.

Further work would be needed to refine the algorithm to accommodate for more realistic factors including access to water and roadways as well as better accounting for the costs involved, but our work serves as a proof of concept and lays the foundation for future research. Implementation of this algorithm would allow public fire planning agencies (such as CAL FIRE and Forest Service) to shift resources to where they would be most effective.



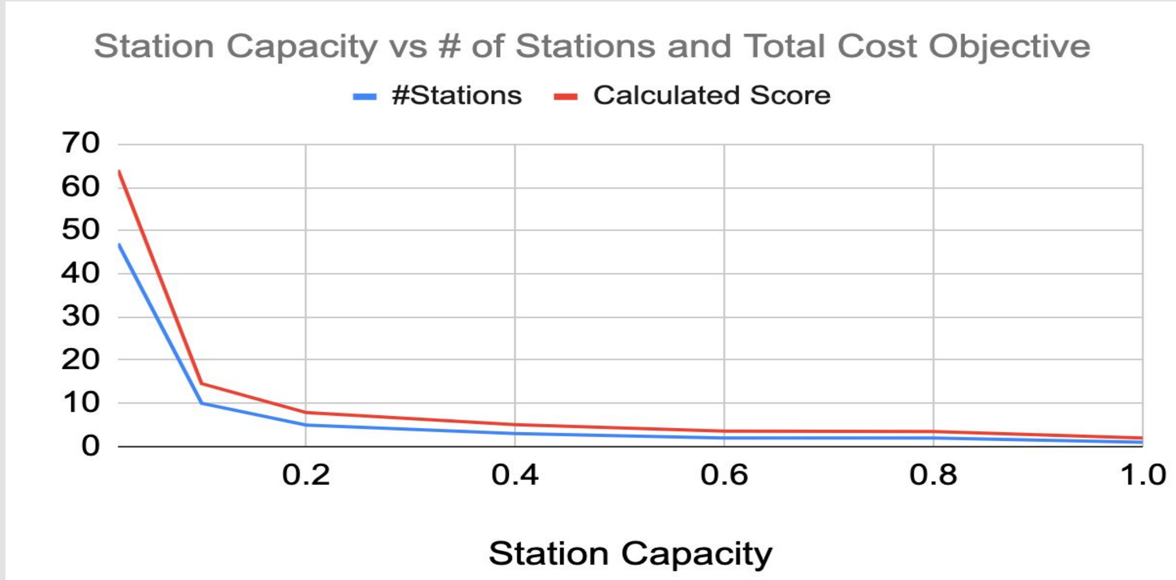

The extreme cases for both varied parameters (capacity and cost) are shown.

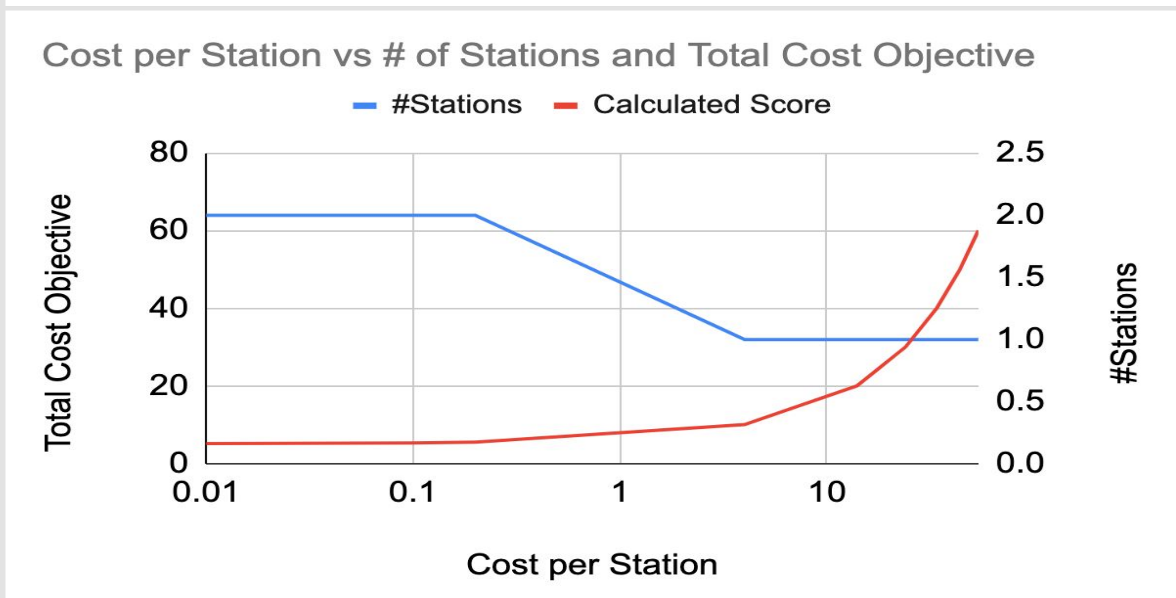
Notes: Red cells represent fire stations placements outputted by the model. The darker green the cell, the more dense the forest. Black cells are boundaries between densities.

## Results

**Takeaways from Sensitivity Analysis:**

- As we increase station capacity for each station, we observe a decrease in # of stations and total cost objective
- Increasing station capacity has diminishing returns
- As we increase the associated cost for building & maintaining each station, we observe a decrease in # of stations and an increase in total cost objective



## Methodology

**Data Collection**

- Land data was pulled from Data Basin in the form of forest density and fire hazard severity matrixes.
- Forest density data was used to decide potential locations of stations and fires.
- Each cell of 1 square mile was classified as either unforested land (A), or light, medium, heavy, and 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

**ILP (Integer Linear Programming) setup**

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

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

Where:
N = number of 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

- **Variables to be computed by model: $x_i$ and $y_{ij}$**
- **Constraints**

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

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

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

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

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

there has to be an integer number of stations

**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)

## Conclusion

**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 cost between a station and a fire.
- Additional data can be added such as proximity to water sources, human population, access to highways, and prioritization of fires based on spread rates
- Improve cost estimates of transportation and construction costs

**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.

## Acknowledgements


Cantlebary, L., & Li, L. (2020). Facility location problem. Facility location problem - Cornell University Computational Optimization Open Textbook - Optimization Wiki. Retrieved August 3, 2022, from https://optimization.cbe.cornell.edu/index.php?title=Facility_location_problem

Conservation Biology Institute. (n.d.). Data basin. Data Basin. Retrieved August 3, 2022, from https://databasin.org/



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