

Determining Optimal Asset Location for Rapid and Efficient Wildfire Suppression: A Simulation Based Approach

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Introduction

- Wildfire incidents continue to pose threats in the US
 - 61,410 wildfire incidents
 - 7.2M acres burned/year (2013-2022)
- Wildfire management efforts are costly
 - 400 wildfire fighter fatalities between 2000-2019
 - \$71.1B and \$347.8B spent on wildfire management efforts

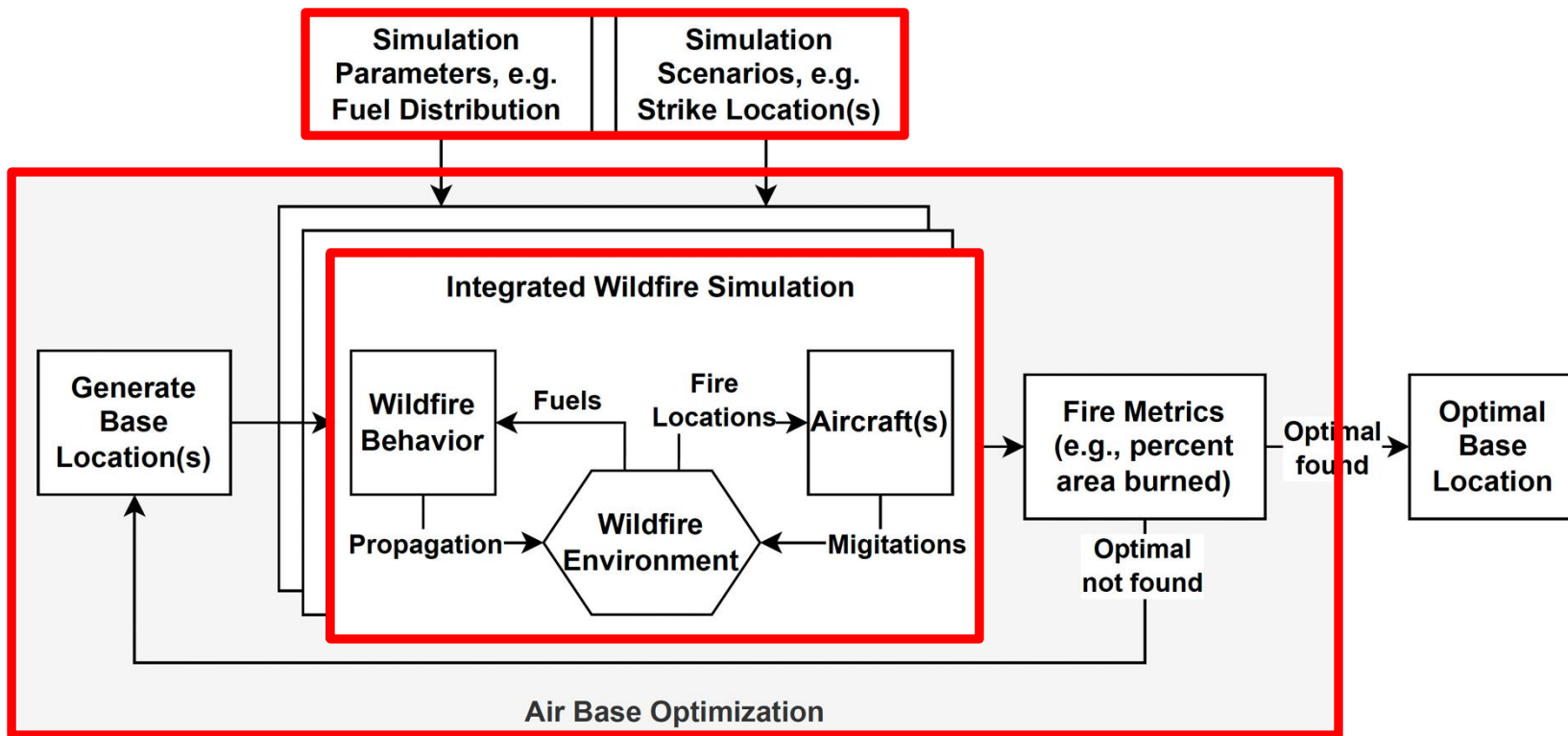
National Interagency Coordination Center, "Wildland Fire Summary and Statistics Annual Report 2022," 2022

Thomas, D., Butry, D., Gilbert, S., Webb, D., and Fung, J., "The Costs and Losses of Wildfires: A Literature Review," 2017

Motivation, Aim, and Approach

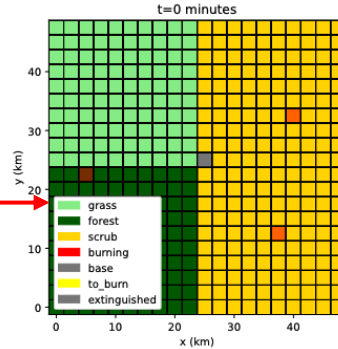
- Increased interest in including UAVs in wildfire management
 - UAVs can conduct fully autonomous suppression efforts
 - They could operate from areas otherwise hard or impossible to access
- Aim: to propose a framework that can facilitate placement of remote UAV airbases for wildfire management
- Approach:
 - Develop a simulation-based approach to optimize UAV base placements
 - Use an optimization algorithm that evaluate and selects potential air base locations that minimize firefighting metrics

Methodology: Overview



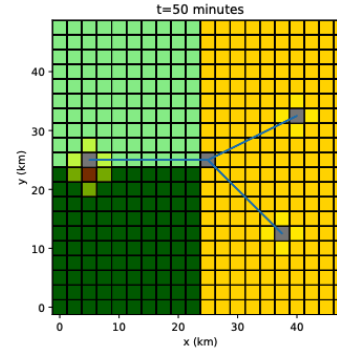
Combined propagation and mitigation of fire over time in a three-fire scenario

Fuel distribution and strike location.



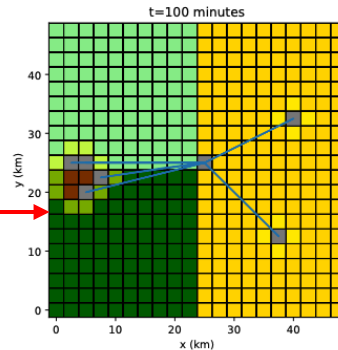
(a) Start of simulation: fires started by 3 lightning strikes.

Aircraft go to a given spot, initially the closest fire location



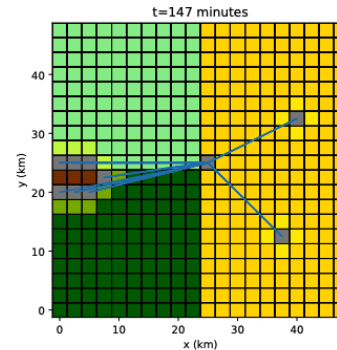
(b) UAV is able to mitigate two fires before they spread.

Simulation ends when fire is contained.



(c) UAV must now contain remaining fire.

Simulation ends when the maximum number of timesteps is reached.



(d) Fire contained.

Methodology: Optimization

➤ Formulation

- To minimize expected fuel burn by optimizing air base locations and address base placement under a specified set of conditions

$$p_b = \frac{100}{n} \sum_{i=0}^n \mathbb{1}_{B \vee E}(i)$$

- p_b is the percent burned,
- n is the number of grid points,
- i is the grid point index,
- B is the set of burning points, and
- E is the set of extinguished points.

$$\mathbb{E}_s \{p_b\} = \frac{1}{n_s} \sum_{s=0}^{n_s} p_b(s)$$

- s is a scenario (e.g., individual set of initial strikes),
- S is the set of scenarios, and
- n_s is the number of scenarios.

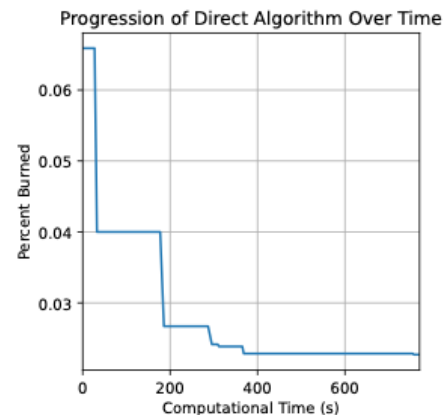
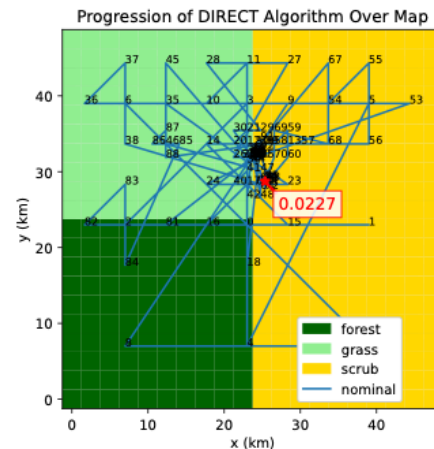
$$\min_{\vec{x}} \mathbb{E}_s p_b(\vec{x})$$

$$s.t. \vec{x}_{min} \leq \vec{x} \leq \vec{x}_{max}$$

- $\vec{x}$ is the design vector (in this case, air base x and y-coordinates), and
- $\vec{x}_{min}$ and $\vec{x}_{max}$ are the bounds of the grid.

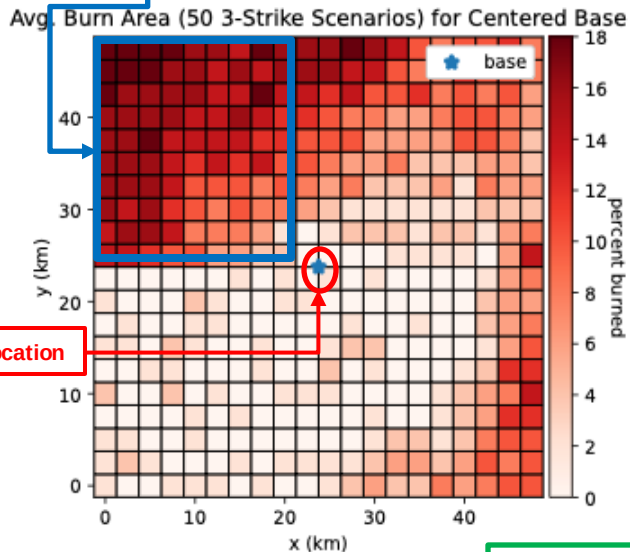
Algorithm: Dividing RECTangles (DIRECT)

- DIRECT Algorithm (Dividing RECTangles)
- Global optimization method dividing and sampling design space iteratively
- High ability to handle non-differentiable objectives
- Performs efficiently in low variable problems
- Displayed robustness over other algorithms like Nelder-Mead in this specific study
- Implementation via `scipy.optimize`

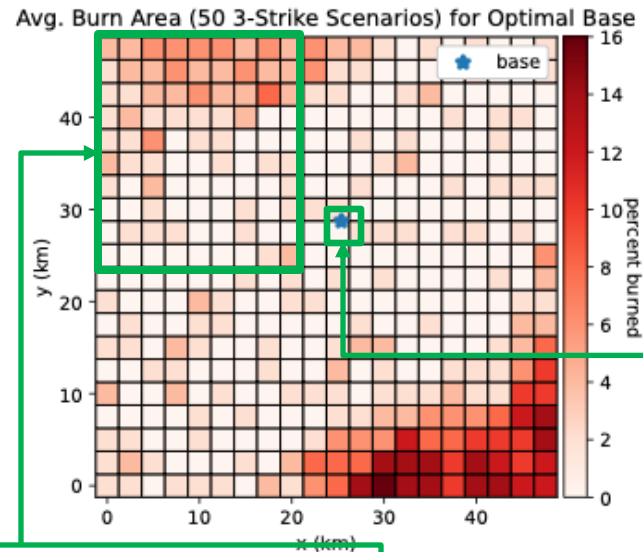


Results

High fire activity, concentrated in the grassland area.



Optimized base location



Considerably reduced average burned area in the grassland areas

	Base Location (km)	Avg. Percent Burned Area
Unoptimized	23.75, 23.75	6.98
Optimized	25.37, 28.73	2.27

Limitations

- Overall assumptions
 - Use of simplistic assumptions in the problem formulation, is it the “right scale?”
 - Aircraft is tasked with always mitigating the closest fire first
- Only the placement of one base is considered in this problem
 - Dictated by the use of DIRECT algorithm
 - DIRECT performs well on low-dimensional problems

Conclusion and Future Work

- Proposed a first step towards optimal UAV base placement for wildfire suppression
- Demonstrated the use of parameterized simulation for modeling fire propagation
- Demonstrated the use of DIRECT algorithm to optimize base location and minimize fuel burn
- Results showed that approach the simulated wildfire response is improved, and the optimization algorithm performs well on this problem
- Future work will seek to address the outlined limitations

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Fmdtools Simulation Package

repo: github.com/nasa/fmdtools

documentation: nasa.github.io/fmdtools/