Efficient Initial Attacks: Analysis of Capacity and Funding Provides Insights to Wildfire Protection Planning

“Creativity is the ability to introduce order into the randomness of nature.”
—Eric Hoffer

Maybe if the two Forest Service research foresters weren’t already friends, they wouldn’t have been so persistent.

One thought his subject matter too complex, with too many variables and uncertainties, to be reduced to a mathematical equation. The other had unshakeable faith that his field of expertise had something to contribute, and trusted his friend’s intelligence and creativity to make the seemingly impossible happen.

Together, Bob Haight and Jeremy Fried, who first met three decades earlier on the University of California-Berkeley campus, created a program that optimizes the distribution and placement of firefighting resources that could potentially allow firefighters to...
reach more wildfires sooner with greater containment success. For firefighting agencies facing rapid growth of population, buildings, and infrastructure in places with relatively high likelihood of high-intensity wildfire, the optimization program couldn’t have come at a better time.

The inspiration to optimize wildland firefighting came from the urban environment, where many metropolitan fire departments seek to strategically place stations so firefighters can arrive on scene within 9 minutes of any call within city limits.

“But it’s not just about getting to more fires sooner,” says co-investigator Fried, a research forester at the Pacific Northwest Research Station in Portland, Ore. “It’s also trying to make sure limited firefighting resources aren’t assigned to locations where they’ll be underutilized.”

To do that, Fried and Haight, a research forester at the Northern Research Station in St. Paul, Minn., would combine two fields of study that at times appeared to be at odds with one another.

Haight first approached Fried on the project a decade earlier, but it wasn’t an easy sell. Fried spent part of his academic career studying wildfires and developing simulation models to accurately predict fire suppression effectiveness and efficiency. Meanwhile, Haight, who came from an economics background, specialized in optimizing systems or processes.

“It’s such a complex system with a lot of moving parts and uncertainties, plus diverse tactics and objectives,” Fried says. “I just didn’t think it lent itself to optimization.”

But Haight persisted, partly because of his conviction that optimization could contribute to improved fire management and because of his confidence in Fried.

“I’ve always had great respect for Jeremy. He’s really hard-working and a creative problem-solver,” Haight says. “Optimization is about identifying the key components of a system, extracting them, and then building a simulation around them. I knew Jeremy could identify those components—or let me know if I was crazy to think it possible.”

The process wasn’t easy, and it was marked by several failed attempts. But eventually Fried and Haight settled on the initial attack phase of wildfire suppression and focused their efforts on the process necessary to minimize the number of fires not contained by initial attack (the 2-hour window after a fire report).

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**BEST OF BOTH WORLDS**

Making the model work would draw on both researchers’ areas of expertise.

Fried had already created a simulation program that could predict the number of fires not contained by initial attack. His California Fire Economics Simulator (CFES2) accounted for location-specific deployment policies, firefighting equipment, tactics, fireline production rates, fire intensity, and fire velocity using probabilistic parameters and functions.

Although simulation models are great for exploring the impacts of marginal changes to a system, they’re less ideal for identifying optimal configurations from scratch. Haight, however, could use information from the simulation model and apply it to a management objective that serves as a proxy for fires that exceed containment—specifically, minimizing the number of fires not receiving a standard response (a situation-appropriate dispatch of firefighting resources) when a fire is reported—to guide decisionmaking.

“Optimization contributes a lot of potential solutions to questions like: Where should resources be located? In what allocations or arrangements?” Fried says. “We take the best solutions from the optimization model and run them through the simulation model to see how they would actually play out.”

The two-step process allowed Fried and Haight to compare the effectiveness of initial attack for alternative resource deployments, dispatching rules, and multi-agency collaboration arrangements.

**KEY FINDINGS**

- A strategic-level model helps in allocating firefighting equipment and staff to effectively support initial attacks and reduce escaped fires. This is useful for optimizing response under current conditions or planning ahead for changes in funding or environmental conditions.

- Consolidating firefighting resources among fewer fire stations reduced about the same number of escaped fires as would a 25-percent increase in initial attack budgets without consolidation. This was for days on which several fires occurred.

- When the model wasn’t allowed to increase the capacities of stations, existing configurations of initial attack resources—designed by local and regional fire managers without any formal optimization—nearly matched the best solutions provided by the optimization model.

**Optimizing the distribution and placement of firefighting resources allows firefighters to reach more wildfires sooner with greater containment success.**
One defined objective for Fried and Haight’s model was to get the typically requested complement of firefighting resources, such as helicopters, fire engines, and bulldozers (“standard response”) to any fire within 30 or 60 minutes, depending on the resource type. The standard response varies by unit. For example, a unit with fewer roads might have more helicopters and fewer fire engines than a unit with more roads. The number of homes in need of protection and the terrain are other factors that influence a firefighting unit’s standard response to a wildfire.

Their optimization was designed to concentrate on days with a minimum of four fire occurrences within a fire protection planning unit. This is because achieving a standard response on such days is challenging and failure to do so makes an escaped fire more likely.

Mathematically, the optimization model would take into account (1) the number of fire planning units, (2) the productivity of all firefighting resources in those units, (3) the number, location, and holding capacity of each fire station in each unit, (4) the set of potential fire locations in each unit, and (5) a set of fire scenarios, each represented as fire occurrences at a set of locations on a single day.

Calculations would operate under several constraints: (1) the combined annual budget for the planning units considered, (2) the annual cost of operating each individual firefighting resource, (3) the maximum holding capacity at each fire station for resources used to fight wildland fires (engines, helicopters, bulldozers, and the people who operate them), (4) the probability of a fire occurring on a particular day and location, (5) the number of firefighting resources, by type, needed to respond to those fires, and (6) the response time of each resource, based on station location and fire location.

With that information, the model can determine the expected number of fires that would not receive a standard response across all planning units, based on budgets, available firefighting resources, station location, and station capacity.

These calculations do have a few shortcomings relative to real-world possibilities. First, the model takes an all-or-nothing approach: it will not send additional resources to a fire beyond the initial dispatch because it assumes that there will be no further benefit to do so. Nor will the model send out a partial response because benefit is assumed to be contingent on delivering the full standard response to the fire. Second, an initial attack resource can be dispatched to only one fire per day. In reality, a resource may be used on multiple fires within a single day. The model also does not attempt to consider days in sequence, meaning that what happens on one day has no influence on what happens on the next.

Despite this simplified view, the model’s utility is in its ability to solve for optimal deployment given uncertainty about the number and location of fires during a severe fire day. A smaller fire is easier to contain than a larger one. Allocating resources in a way that minimizes the number of escaped fires on severe fire days lays the foundation for a successful initial attack.

**DOING MORE WITH LESS**

To test the model’s practicality, the researchers applied it to 1.2 million hectares of forest and rangelands in California’s central Sierra Nevada. The region encompasses three contiguous fire units administered by the California Department of Forestry and Fire Protection (CAL FIRE).

After assessing the current configuration (base case) of firefighting resources, the researchers compared those results against scenarios that manipulated resource allocations, station capacities, and budgets.

The model identified a deployment configuration that reduced the number of fires not receiving a standard response by 40 percent, compared to the current configuration. This was achieved by shifting existing resources among units. The unit with the most demanding standard response requirements received additional bulldozers and helicopters, and the cost of operating this additional machinery was covered by the savings incurred by maintaining fewer fire engines.

Although the model found new deployments that increased the number of fires receiving the full complement of required resources on days when four or more ignitions occurred, those new configurations were no more effective in minimizing the number of fires not contained by initial attack than the existing configuration of resources.
"That this optimization within the current constraints did not identify a better configuration for containment success suggests that fire planners have done extremely well in developing the current deployment," Fried says. This can be empowering feedback for planners and land managers. The subsequent optimizations, based on different budget and capacity scenarios, are helpful as they suggest approaches for exploring further to improve efficiency and effectiveness.

When station capacity constraints were removed with no limit to the amount of equipment or personnel a station could house, the new deployment configuration resulted in 1.92 fires per day not receiving a standard response (compared to 2.86 base case) and a 9-percent reduction (0.522 to 0.478) in the number of fires per day not contained by initial attack. Fire engines and bulldozers were concentrated at 13 fire stations instead of 32. In the base case, seven helicopters were distributed across four locations. In this optimization, four helicopters were added, bringing the total to 11, and they were deployed to fewer locations, with seven of them housed at a single, centrally located air base.

"The concentration of resources might add benefit, not accounted for in our models, for reducing expenses on infrastructure maintenance, thereby freeing up funds for more firefighting resources," Fried says. "It is possible that at least some of the savings might be needed to cover the cost of adjusting station capacity, such as the construction of additional buildings to house equipment or staff. These costs would be one-time costs, however, and the savings would continue," he explains. "The model results tell us that concentrating resources may be better because more fires receive the intended initial attack response with this deployment, and fewer fires escape initial attack."

As expected, increasing the budget had significant impacts on firefighting capabilities. A 25-percent budget increase reduced the average daily containment failure rate from 0.537 to 0.488 when fire station capacity was constrained and from 0.531 to 0.477 when it wasn’t.

Conversely, budget reduction scenarios provided insights on how proactively consolidating resource locations could enhance overall station viability. In the fixed-capacity scenarios, the reduced budgets (and, therefore, resources) resulted in nine fewer stations being used because there weren’t enough resources to be distributed to all the locations. In the high-capacity station scenarios, budget reduction closed only four stations because, although the number of resources was reduced, most of the consolidated stations remained viable.

Another case for the benefit of consolidation emerged after the effects of budget changes were charted for the expected number of fires not contained by initial attack and the number of fires that didn’t receive a standard response. In the current budget with no station capacity limit scenario, the containment failure rate was only slightly greater than for the 25-percent budget increase, fixed-capacity scenario.

The analysis system developed by Fried and Haight focused on the efficiency of alternative resource deployments for initial attack on wildland fires. In practice, however, firefighting resources may serve additional community needs, such as emergency medical response. These additional protection services for outlying services were not considered in this analysis system.
FROM COMPUTER TO COLLABORATORS

Fried and Haight’s work with CALFIRE was a test case. It showed it was possible to construct a methodology that could optimize the allocation of firefighting resources. Although local fire planners would need to rely on programming specialists to synthesize all the data and run the permutations, it nevertheless invites the discussion that such optimization is possible.

“The most important result of this model is the idea, not the computer program itself,” Haight says. “Our intention isn’t to create a decision-support system that we’d try to give to managers. We want to get them to think about the results and think in broader terms about what they mean.”

Fried and Haight published an exploratory study in 2007 that focused on the deployment of a single type of resource (fire engines) in a single fire planning unit. Their latest work is directly applicable in the real world because it considers all firefighting resources (except air tankers) and accounts for cooperation among adjacent planning units. Fire planners are taking note of these improvements.

“This shows that the right kind of optimization approach, when combined with a simulation that accounts for the complexity of wildland firefighting, can help identify the solutions that are most likely to provide improvements over the status quo,” says J. Keith Gilless, chairman of the California Board of Forestry and Fire Protection.

The findings also are attracting an international audience. Yohan Lee, a graduate student from South Korea, was one of Fried and Haight’s collaborators at Oregon State University (OSU). He was mentored by another collaborator, Heidi-Jo Albers, an OSU professor. Lee has continued to advocate for the idea, not the computer program itself,” says J. Keith Gilless, chairman of the California Board of Forestry and Fire Protection.

“For further reading


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