

Science

FINDINGS

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"Science affects the way we think together."

Lewis Thomas

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



Kari Greer

Severe wildfires pose a greater threat to life and property as more people build homes in relatively remote locations.

"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

IN SUMMARY

Large wildfires in the United States pose significant challenges to fire management agencies charged with protecting lives, property, and natural resources. A vigorous initial response to a wildfire, a process referred to as "initial attack," can greatly reduce the likelihood of the fire becoming larger and causing substantial damage.

Successful initial attack depends on deploying the right number and kind of firefighting resources in a timely way. As people build homes where high-intensity wildfire is likely, they place greater strain on finite staffing and budgets. Fire planners have sought analytic guidance in designing an efficient initial attack system that minimizes both escaped fires and money spent on underutilized firefighting resources.

Forest Service scientists and colleagues with Oregon State University developed a system that combines historical fire data and fire simulation programming with an optimization protocol to recommend the allocation of equipment and staff that will most effectively support initial attack and reduce escaped fires.

In an analysis of three fire units in the central Sierra Nevada mountains of California, researchers discovered that by consolidating equipment and staff into fewer stations strategically selected based on historical fire patterns, crews could effectively reach as many fires and stop the occurrence of escaped fires at the same level as if their initial attack budgets had been increased by 25 percent.

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.

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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.



“Simulation is about trying to represent reality,” Fried says. “Optimization tries to represent an abstraction of that reality mathematically to come up with the best answer.”

The mathematical reduction of the problem necessary to make optimization possible seemed incompatible with the wildfire system, and Fried had already witnessed multiple unsuccessful attempts by economists and operations research scientists to produce constructive tools in this realm.

“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).

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.



Optimizing the distribution and placement of firefighting resources allows firefighters to reach more wildfires sooner with greater containment success.

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.

THE MATHEMATICS OF FIREFIGHTING

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.

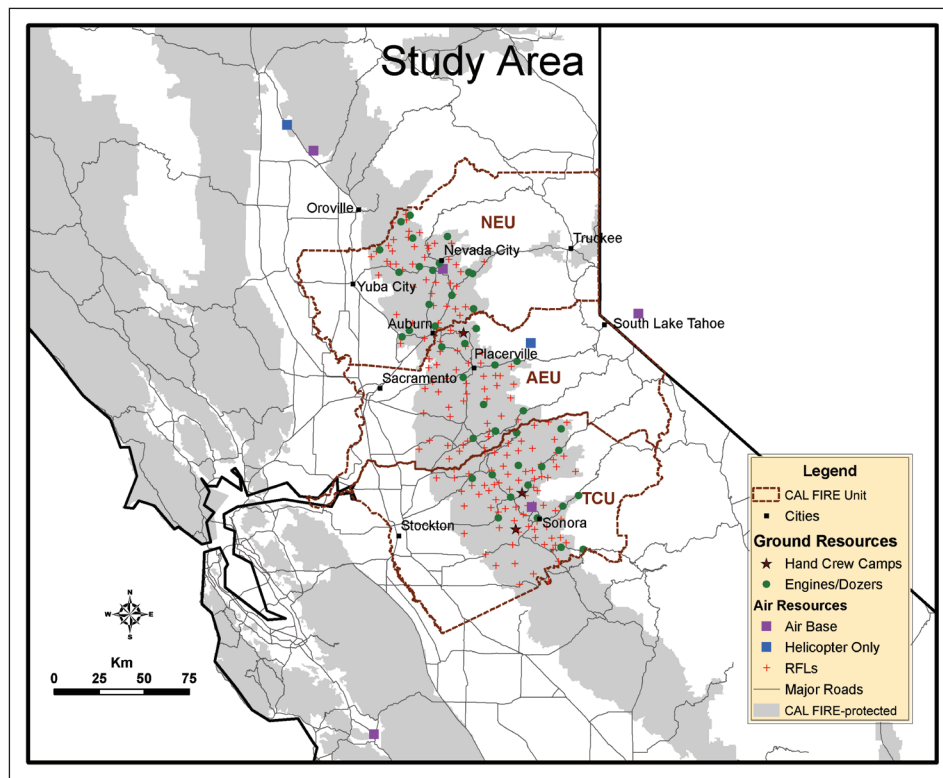
Mathematically, the optimization model would take into account (1) the number of fire planning units, (2) the productivity of all firefighting resources in those units, (3) the number, location, and holding capacity of each fire station in each unit, (4) the set of potential fire locations in each unit, 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.

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



The study area consisted of three CAL FIRE administrative units in the central Sierra Nevada region of California: Nevada-Yuba-Placer (NEU), Amador-El Dorado (AEU), and Tuolumne-Calaveras (TCU).

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.

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



California Office of Emergency Services

The optimization based on the current budget revealed efficiencies by placing additional bulldozers and helicopters in the unit with the most demanding fire scenarios. At left, a helicopter uploads fire retardant.



California Office of Emergency Services

The cost of operating additional bulldozers and helicopters was offset by deploying fewer fire engines, under the current budget optimization.



California Office of Emergency Services

The number of hand crews deployed during an initial attack remained about the same under the current budget optimization.

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 CAL FIRE 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 Gilles, 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 model, conducting a second analysis of initial attack for the Korean Forest Service as part of his dissertation, and sharing lessons learned after returning home to South Korea.

“South Korea has many mountainous areas with limited road access, so helicopters are our main firefighting resource,” says Byungdoo Lee, a fire specialist with the Korea Forest Service. “So far, fire experts



LAND MANAGEMENT IMPLICATIONS



- This analysis system suggests the benefits of exploring alternate configurations of fire-fighting resources when faced with constrained budgets.
- With a budget increase, the analysis system helps guide decisions about what firefighting resources to acquire and where then to most effectively deploy them.
- Constraints in budget and fire station capacity limit the number of initial attack resources and influence the appropriate mix of deployed resources because of the differences in cost and productivity associated with each resource type.
- The analysis system can be extended to any geographic area with information about historical fire occurrence and intensity, firefighting resource deployment policy, annual costs and budgets for operating firefighting resources, the maximum holding capacities of fire stations for firefighting resources, and the response time of each resource, based on the locations of fires and fire stations.

operate these resources based on their experiences. However, by using the advanced model, I expect that we can operate those resources more efficiently than before.”

The model’s ability to make adjustments based on budget changes is also appealing, according to Gilles, who noted that CAL FIRE had commissioned Fried’s CFES2 simulation program in part to support budget change proposals.

“Indications that potential gains in initial attack effectiveness could be achieved by redeploying resources to fewer locations to enhance depth on days of high fire activity has real-world implications. This merits further exploration and analysis for all fire service agencies facing the kinds of resource protection pressures we do in California,” he says.

First comes thought; then organization of that thought, into ideas and plans; then transformation of those plans into reality. The beginning, as you will observe, is in your imagination.
—Napoleon Hill, author of “Think and Grow Rich”

FOR FURTHER READING

Fried, J.S.; Gilles, J.K.; Spero, J. 2006. Analysing initial attack on wildland fires using stochastic simulation. *International Journal of Wildland Fire*. 15: 137–146. <http://www.treesearch.fs.fed.us/pubs/24567>.

Haight, R.G.; Fried, J.S. 2007. Deploying wildland fire suppression resources with a scenario-based standard response model. *INFOR*. 45(1): 31–39. <http://www.treesearch.fs.fed.us/pubs/13567>.

Lee, Y.; Fried, J.S.; Albers, H.J.; Haight, R.G. 2013. Deploying initial attack resources for wildfire suppression: spatial coordination, budget constraints, and capacity constraints. *Canadian Journal of Forest Research*. 43: 56–65. <http://www.treesearch.fs.fed.us/pubs/42818>.



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