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How Operations Research and Management Science Can Help Address the Wildfire Crisis

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Fire is a natural ecosystem process that helps maintain and revitalize healthy landscapes, but wildfires can pose significant threats to public and firefighter safety, property, water and air quality, and other values. Finding an appropriate balance of managing for the beneficial and detrimental impacts of fire can be a challenge, and in many forest and grassland ecosystems, a

legacy of fire exclusion and changes in land use patterns has led to unnatural accumulations of flammable vegetation and increasing wildfire hazard. Wildfire management entails a breadth of actions taken before, during and after fires occur, including fuel or vegetation management, prevention, detection, resource staging and deployment, incident response and recovery.

Wildfire managers must resolve complex decisions often characterized by considerable uncertainty and trade-offs across multiple objectives (e.g., cost, safety, environmental impact). Such challenges are compounded by a changing climate that is exposing an increasing amount of assets at risk and putting an ever-growing strain on wildfire management systems across the globe. Wildfire management agencies are accustomed to sharing their resources on regional, national and even global scales. Unfortunately, changing spatial and temporal patterns of ignitions and drought are important drivers that are contributing to more and more parts of the world experiencing elevated fire loads at the same time. Such synchronous fire activity is stretching resources thin and threatening to overwhelm suppression capabilities and compromising the ability of wildfire management agencies to appropriately respond to fires. These converging forces create special challenges for fire managers that we believe operations research and management science (OR/MS) specialists can help resolve.

Even though OR/MS specialists have been studying wildfire management since the early 1960s when Shephard and Jewell (1961) [1] explored the possibility of bringing O.R. to bear on wildfire management problems, there remains a noticeable need to bridge the gap from research to implementation [2-4]. Thompson et al. (2019) discussed some of the challenges to bringing predictive and prescriptive analytics to bear on wildfire management problems, arguing that strategies to address human and organizational factors are likely necessary to fully capitalize on OR/MS [5]. We believe there are at least four important issues at play here: ***relevance***, ***culture***, ***competence*** and ***trust***.

First, managers are more likely to seek out and use tools that address real-world problems and align to organizational goals. Second, there can be barriers to the adoption of well-conceived tools due in part to predispositions to rely more on intuition and expert judgment, requiring an organizational “data-driven cultural change” [6] that catalyzes behavioral changes and emphasizes performance. Third, to ensure managers can effectively use OR/MS tools, organizations should cultivate strong analytical skills in managers so they can leverage both judgment and analysis. Lastly, development and delivery of OR/MS tools are often enhanced through science-management partnerships based on trust.

We found it is not only essential but also rewarding for O.R. specialists to invest in building relationships with managers. Doing so helps O.R. specialists further their understanding of the nature of the problems they have been invited to investigate and the level of analytical complexity required, helps ensure they will solve the right problem, and increases the likelihood that their results will be implemented. Here, we provide two illustrative examples and share our lessons of how OR/MS has been successfully integrated in wildfire management.

Optimal Location of Aerial Firefighting Assets

A project completed by MacLellan and Martell (1996) illustrates the importance of the four "implementation" factors outlined above [7]. The Ontario Ministry of Natural Resources (OMNR) contacted Martell and asked if he could assist their internal working group that was responsible for recommending where their airtankers should be home-based. We believe he was invited to participate in that process in part because of his involvement in an earlier analysis of Ontario's initial attack system [8], which was motivated by the need to update its airtanker fleet. Fortunately, one of Martell's graduate students (MacLellan) had worked as a firefighter in Ontario and therefore had a sound understanding of fire suppression operations, including the use of airtankers in Ontario. They worked closely with the internal working group and developed a mathematical programming model that was used to inform the new airtanker home-basing strategy for the 1993 and subsequent fire seasons. As time passed, ensuing decisions to home base most of OMNR's airtankers at three airports were driven by airport facilities and infrastructure investment factors that were not considered by MacLellan and Martell and the working group, but the benefits of the trust that was built and impact of infusing analytical thinking into such decisions endured.

The fact that these O.R. experts were invited to participate in the airtanker home-basing project suggests the fire managers involved felt that the tools that Martell and MacLellan could develop would be *relevant* to their urgent "real-world" problem. Because the fire managers and researchers participated in previous O.R. projects in Ontario, they developed what Martell et al. (1999) characterized as a *competent* decision-analysis *culture* in Ontario. McFayden et al. (2020) have discussed the importance of expert judgment in wildfire management, but that crucial aspect of fire management did not preclude Ontario's wildfire managers from considering the use of an analytical approach to inform their airtanker management [9]. Finally, as noted above, Martell's involvement in the initial attack study described in Martell et al. (1999) [10] and MacLellan's practical experience as a firefighter engendered the *trust* that we believe is essential for productive collaboration between wildfire managers and O.R. specialists.

"Moneyball" for Fire and Analytics for Incident Response

More recent work in the United States similarly highlights the importance of these four implementation factors. For many years, the interdisciplinary Wildfire Risk Management Science (WRMS) Team at the U.S. Department of Agriculture (USDA) Forest Service Rocky Mountain Research Station has been working to improve decision support systems to better meet the needs of incident management teams responding to large wildfires often covered in the media. Because the team is embedded in a public land and fire management agency, there is an expectation for science that is *relevant* to agency needs, which is enhanced through leveraging connections to agency staff and managers. Specifically, although many forms of decision support existed to help managers assess potential fire behavior and impacts to assets, there was an opportunity to increase the informational basis to identify opportunities for firefighters to safely and effectively engage the fire.

In 2016, scientists on the WRMS team helped develop and refine fire analytics intended to bridge

this gap by providing operationally relevant information on suppression opportunities and challenges [11-13]. It took some time to overcome *cultural* barriers, including some aversion not only to shiny new tools from research and development (R&D) but also to the language we had been using – for example, “data-driven decision-making” and “evidence-based management” – hence the switch to the “Moneyball for fire” [14] analogy, borrowing from the book by Michael Lewis as well as broader lessons from the sports analytics revolution. Today, these analytics are institutionalized, freely available through an online dashboard, regularly requested and used by fire managers for real-time incident decision support (see Figure 1 for an example) and embedded into preseason planning exercises. As the familiarity with and use of the tools have grown, so too has the *competence* of fire managers to effectively interpret model results and leverage insight to inform decision-making, synergistic with agency investments to build capacity by hiring more fire analysts. Lastly, a lesson we have learned along the way is that *trust* can be cultivated and strengthened in many ways. In addition to emphasizing relationship building, and much like the prior example from Canada, we have found that OR/MS teams with members having previous firefighting experience are often viewed with greater credibility and receptivity. Once built, the relationships between researchers and fire managers can blossom into fruitful, long-term partnerships that expand the scope, scale and impact of O.R. analyses in the field. For example, fire managers that previously used the suppression analytics proactively engaged WRMS researchers as they embarked on a project reorganizing a set of local dispatching centers.

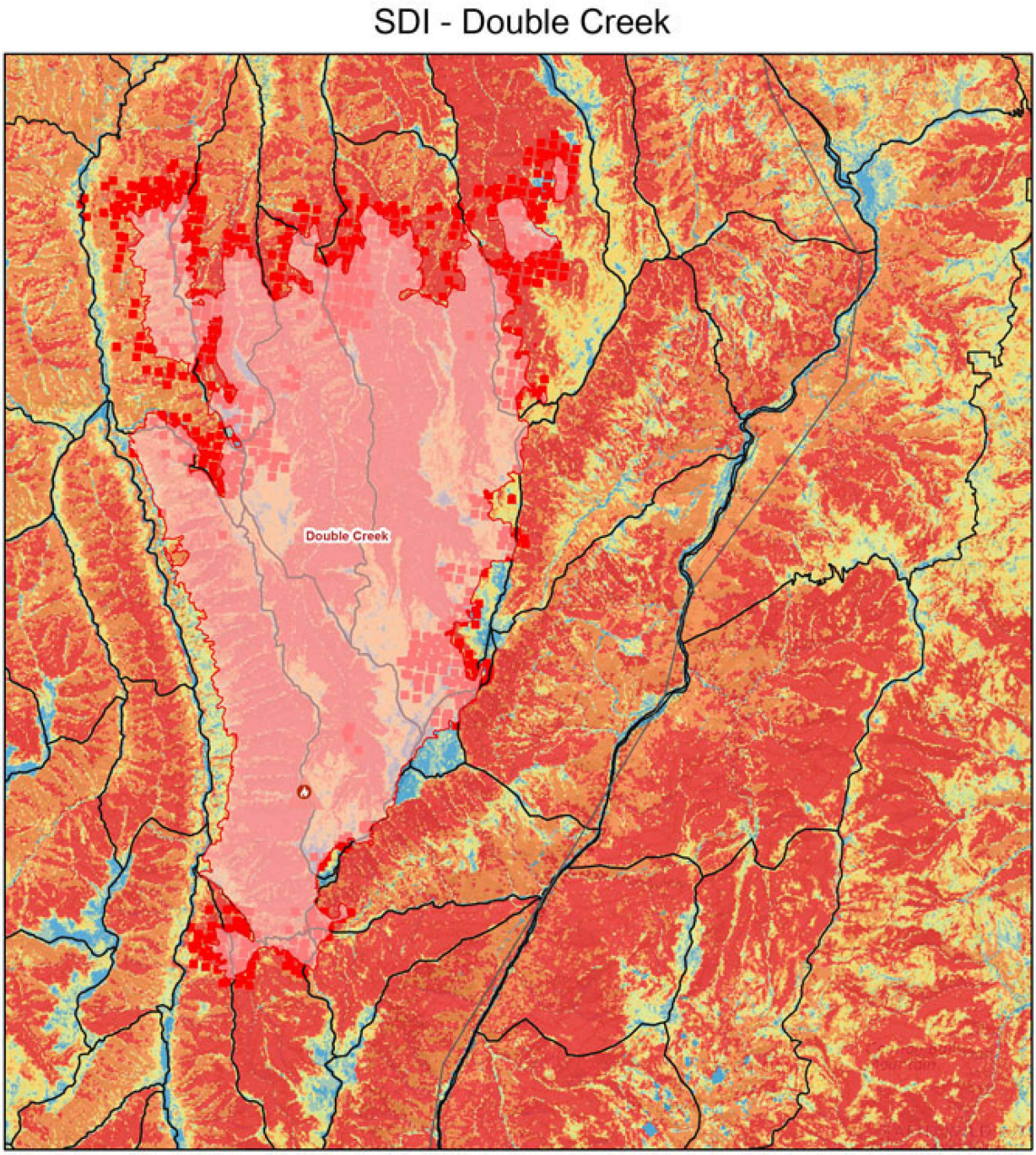

Figure 1. *Illustration of the Double Creek Fire in Oregon on September 7, 2022, overlaid on a map of the Suppression Difficulty Index (SDI) and Potential Operational Delineations (PODs). These are two of many analytical tools fire managers use to evaluate strategic and tactical options regarding deployment of firefighting resources. The warmer colors on the map indicate areas of greater suppression difficulty and elevated firefighter hazard, and the black lines represent potential control locations identified by managers in advance of the fire. These products are housed in an online dashboard provided by the USDA Forest Service's Risk Management Assistance Program (see [15]). Figure source: Bradley Pietruszka.*

Future Directions

The future of wildfire management will be one of growing challenges. In the face of elevated and growing risks and degraded capacity, it is imperative that wildfire response systems operate more efficiently and effectively. We urgently need viable solutions that will empower wildfire managers to do more with less and manage the flammable landscapes and communities at risk without compromising the health and well-being of the fire personnel upon which the system relies. This will likely require rethinking how interagency wildfire response systems can better leverage enhanced logistics, operations research and proven fire analytics tools.

There are many areas of opportunity for OR/MS to provide actionable insight. Some salient topics include (1) landscape-level fuel management that addresses fire suppression cost-effectiveness, ecological impacts and threats to public health and safety; (2) regional, national and international sharing of suppression resources; (3) integrated solutions for rapid fire detection and deployment of resources along with response strategies over the duration of fire events; and (4) infusing of structured decision-making principles, including the importance of proper problem formulation, into strategic prioritization and decision processes. To do so effectively, OR/MS specialists may need to include personnel with firefighting experience on their teams and spend extended periods of time working with managers in the field to understand their needs, develop useful solutions and ideally create a virtuous cycle in which success breeds greater investment and broader adoption of science-driven solutions.

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