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A Decision Framework for Evaluating the Rocky Mountain Area Wildfire Dispatching System in Colorado

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Abstract. In recent years, the state of Colorado has experienced extreme wildfire events that have degraded forest and watershed health and devastated human communities. With expanding human development and a changing climate, wildfire activity is likely to increase, and wildfire management agencies will be challenged to sustain landscapes and the ecosystem services they provide. A critical element of the United States' federal-, state-, and local-level multiagency wildfire response is the interagency dispatching system, which facilitates the ordering, mobilization, and tracking of firefighting resources to and from wildfire incidents—a role that is likely to increase in both importance and workload in the future. Given increasing demands, it is worth considering ways to improve efficiencies, capacity, and capability within the current Colorado dispatching system. With this, the Rocky Mountain Coordinating Group (RMCG) and the Rocky Mountain Area Fire Executive Council (RMA-FEC) sought to reorganize the dispatching system, beginning with exploration of changes to dispatching zone boundaries and the number and location of dispatching centers throughout the state. Here we describe a multiyear research–management partnership with the RMCG and RMA-FEC to apply a structured decision-making process to guide this reorganization effort. We highlight the steps used in a participatory process that involved local decision makers and included iteratively revising and clarifying the problem statement, developing objectives and translating them into measurable attributes, building a multiobjective optimization model to generate and compare alternatives, and communicating a recommended alternative that was ultimately adopted. To conclude, we discuss insights from our experience and highlight opportunities for similar work to support efficient wildfire management elsewhere in the United States.

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Introduction

The global increase of extreme wildfires, driven in part by climate change, presents myriad threats to social and environmental sustainability (Balch et al. 2020, United Nations Environment Programme 2022). Impacts include loss of human life (Cruz et al. 2012), damaged or destroyed structures (Caggiano et al. 2020), adverse health outcomes from smoke exposure (Abdo et al. 2019, Navarro et al. 2019, Stowell et al. 2019), impaired water quality (Robinne et al. 2021), and loss of forest resilience and ecosystem services (Stevens-Rumann et al. 2018, Coop et al. 2020). The state of Colorado presents a microcosm of the growing wildfire problem, with growing risk to human communities (Liu et al. 2015, Meldrum et al. 2022), projections of increased postfire hydrologic risk (Touma et al. 2022), and concern over forest loss and degraded forest recovery following high severity fires (Rodman et al. 2020). In recent years, the state experienced extreme fires, including the largest (the Cameron Peak fire of 2020) and most destructive (the Marshall Fire of 2021) in state history.

An essential component of safe and effective wildfire response in Colorado is the dispatch system, which facilitates the ordering, timely mobilization, and tracking of firefighting resources to and from wildfire incidents. The dispatch system is comprised of multiple dispatch centers that service different areas of the state and is a part of a larger interagency system run by the Rocky Mountain Area Coordinating Group (RMCG) and overseen by the Rocky Mountain Area Fire Executive Council (RMA-FEC). These dispatch centers work behind the scenes of the wildland firefighting system to ensure efficient and effective mobilization of local resources for rapid response to new ignitions as well as coordination of incoming and outgoing firefighting resources to meet demand on larger, more complex, and longer duration fires. The system aims to provide quick mobilization times and effective communication with firefighters, fire managers, and other dispatching centers.

The current dispatching system in Colorado was designed 40 years ago and is not built to support the increased demand for dispatch services due to longer and more intense fire seasons and a changing climate. Increasing fire activity, future weather extremes, and greater demand for community and landscape protection will undoubtedly put further strain on an already strained dispatch system, as well as the broader wildfire response system in Colorado (Belval et al. 2020a, 2022; Cattau et al. 2020; Abatzoglou et al. 2021; Coop et al. 2022). Therefore, in 2018, the RMCG and RMA-FEC initiated a phased, multiyear reorganization and consolidation project for the dispatch system in Colorado that resulted in the formulation of the Decision Efficiency Team. The team's purpose was to develop alternatives for the future of the dispatching system in Colorado and to assess these alternatives using both qualitative and quantitative attributes. Thus, this paper describes an application of decision analysis methods to a reorganization of the wildland fire dispatching system, a relevant and growing socioecological sustainability challenge.

Decision support tools have been designed to support the allocation and deployment of wildland fire resources in the past. For example, optimization and simulation models have been built to determine how many and which personnel and equipment should be sent to each fire ignition (Haight and Fried 2007; Hu and Ntaimo 2009; Lee et al. 2013; Wei et al. 2015a, b), locations of fire stations (Sakellariou et al. 2020b), and fire suppression resources (Chow and Regan 2011, Pacheco et al. 2014, Sakellariou et al. 2020a), and how to dispatch and route aircraft to support wildland fire response (MacLellan and Martell 1996, McFayden et al. 2020). Some of these models have been successfully implemented and used in day-to-day operations, in developing guidelines around required personnel and equipment capacity or in developing policy regarding appropriate response. One characteristic that all the past work has in common is the assumption that there is already a capable dispatching system in place that could receive the request for response personnel, determine who and what is best to send, communicate the assignment with the associated personnel, and track the status of the personnel and equipment once they are assigned. The design of the system itself has not been addressed, and addressing that issue required a more comprehensive decision-making approach.

Decision makers in this space regularly make multiagency decisions using techniques drawn from the muticriteria decision analysis literature. For example, the Rocky Mountain Multiagency Coordination Group meets daily at the height of the Rocky Mountain fire season to allocate fire suppression resources from multiple agencies to fires burning on multiple agencies' jurisdictions. This process includes ranking fires using a multicriteria decision matrix and using a consensus-based decision-making process (Rocky Mountain Coordinating Group 2022). Although the daily decisions on resource allocations are operational and the problem of dispatching is strategic (Keeney 1992), the current processes in place mean that the decision makers are familiar with the practice of making decisions that balance multiple criteria. In addition, these decision makers are a part of the land management community, which has seen increased application of decision theory in making complex decisions that involve many stakeholders with varying and competing objectives (Huang et al. 2011, Runge et al. 2020). For example, structured decision making has successfully been applied to complex environmental management problems with diverse stakeholders, difficult trade-offs, and potential for significant impacts (Gregory 2012; Marcot et al. 2012; Runge et al. 2015, 2020; Martin et al. 2019; Hemming et al. 2022). A few recent examples include developing recovery and management plans for endangered species (Brazill-Boast et al.

2018, Marcot et al. 2021, Runge et al. 2020) and developing a long-term fuel management strategy (Gazzard et al. 2020).

In early 2020, the authors of this paper were asked to join the Decision Efficiency Team as consultants on decision analysis and structured decision making. We subsequently participated in multiple meetings and workshops to guide and support the decision process from problem formulation through to the decision point. The team's work adapted a variety of techniques rooted in decision analysis principles and practices. We relied heavily upon the PrOACT model (Hammond et al. 2002), a specific framework for structured decision making (Gregory 2012), to communicate the principles and phases of structured decision-making process with stakeholders and decision makers. The PrOACT model breaks the decision-making process into several core elements: defining the **pr**oblem, articulating **o**bjectives, generating **a**lternatives, assessing **c**onsequences across alternatives, and considering **t**rade-offs between alternatives (Hammond et al. 2002, Gregory 2012). Within the PrOACT framework, we utilized previously developed tools including building objectives hierarchies (Granger 1964), the development of attributes (Keeney and Gregory 2005), an integer program (IP; Wolsey 2021), and identification of nondominated solutions (Luc 2008), visualization tools (Qin et al. 2020), and development of a consequences (Gregory 2012) and ranking table (Hammond et al. 2002). Therefore, we organize this paper around the core elements of a decision within the PrOACT framework with one section dedicated to describing the project details and timeline.

Project Details and Timeline

The dispatch system reorganization was split into two cleanly separable phases. The first phase of the decision process was intended to finalize the number and geographic boundaries of dispatching zones along with the number and location of dispatching centers through the state. Later, a second phase intended to make determinations regarding organizational structure, staffing, and center design (e.g., office layout and communications infrastructure). This manuscript only addresses the first phase of the decision process. These stages were considered separable, as the outcomes associated with the first-stage decisions were not reliant upon any of the decisions made in the second stage. The second stage of the project is primarily the implementation of the first-stage decisions.

As is often the case in structured decision making, the process through the PrOACT steps were not linear, but rather, several steps were revisited multiple times throughout the project (Hammond et al. 2002, Gregory 2012). Although we delve into each of the stages in detail in the following sections, it is helpful to have a timeline of the project to see what order different activities occurred and how they link to the PrOACT steps. Table 1 provides the project timeline for reference throughout the manuscript.

There were three key sets of people involved in the decision-making process: the decision makers themselves (i.e., the RMA-FEC), the Decision Efficiency Team, and a wide group of stakeholders. Decision makers on the RMA-FEC included representatives from the U.S. Forest Service, Bureau of Land Management, Bureau of Indian Affairs, U.S. Fish and Wildlife Service, National Park Service, Colorado Department of Fire Prevention and Control, and Kansas State Forest Service. Because the decision could have far-reaching consequences, a wide variety of stakeholders was involved including dispatching center personnel, agency administrators, county sheriffs, agency fire management staff, incident responders, local line officers, and personnel who interact with dispatch (i.e., engine captains).

In 2019, the RMCG formally tasked the team with specific expectations around developing alternatives and considerations such as cost of living and desirability of different dispatch center locations. The team performed initial outreach to multiple stakeholders to develop a set of feasible zone and location alternatives that would specifically address recruitment and retention issues. During these stakeholder meetings interagency partners came up with possible alternatives that reduced the number of centers in Colorado from six to between two and four. Although there are limitations to using brainstorming sessions to generate solutions (Isaksen and Gaulin 2005), these sessions did provide the team with a variety of practical input regarding zone boundaries, which was carefully considered as sets of zones were created. The first set of zone boundaries was then provided to the stakeholders for comment, and in response to this second round of stakeholder input, the four draft alternatives for dispatch zone boundaries (including the status quo) were refined and finalized.

Table 1. A Timeline of Activities for the Rocky Mountain Area Dispatch Efficiency Project

Activity	PrOACT step	People involved
Dispatching team created	Define problem	Decision makers
Initial stakeholder meetings	Define problem	Stakeholders
Dispatcher survey	Objectives and attributes	Dispatchers (surveyed), dispatching team (analysis)
Developing zone boundaries	Alternatives	Dispatching team
Follow-up stakeholder meetings to assess boundary alternatives	Alternatives, objectives, and attributes	Stakeholders
Revise zone boundaries	Alternatives	Dispatching team
Obtain additional performance attributes	Consequences	Dispatching team
Stakeholder meeting to assess boundary and city alternatives	Consequences and trade-offs	Stakeholders
Decision-maker meeting	Define problem, objectives, and attributes	Decision makers
Develop integer programming model	Trade-offs	Dispatching team
Trade-off analysis workshop	Trade-offs, decision	Decision makers
Initial decision announced with supporting documentation provided, comments solicited	Decision	Decision makers and stakeholders
Comment discussion session	Trade-offs	Decision makers
Final decision announced	Decision	Decision makers

After the development of zone boundary alternatives, the authors of this paper were asked to join the team as consultants to help structure a trade-off analysis workshop (February 1–3, 2021) comparing the draft alternatives, based on previous work facilitating workshops and providing decision support for the wildfire management community (Thompson et al. 2016, Calkin et al. 2021, Belval et al. 2022). The intent of the meeting was to allow dispatchers and dispatch center users to evaluate the impacts of the proposed alternatives. However, it quickly became clear that stakeholders did not agree on the problem being solved, or what critical impacts needed to be evaluated. The final report (Belval et al. 2020b) on the workshop's outcomes stated that the participants had

> two main views of the current definition of the problem that the group was there to assess. One group of participants was inclined to think strategically about the program and wanted to work toward building an organization that is effective and efficient going into the future. A second group of participants was certain that the sole goal of the Dispatching Efficiency Project is to address the issues stated in the 2017 white paper, which focused only on recruitment and retention and seemed to see strategic restructuring as outside the bounds of the current decision. Without agreement on the actual problem, determining objectives by which to measure alternatives as well as determining the scope of possible alternatives was not feasible.

In response to the confusion shown in the stakeholder group, the team decided to revert to focusing on problem definition and to adopt a more formal and structured decision process. It was at this point that the team reframed the process using the structured decision-making framework, specifically through the steps of the PrOACT model (Hammond et al. 2002).This decision-making framework breaks the decision process into five main categories: problem, objectives, alternatives, consequences, and trade-offs. The team chose to use the PrOACT model for three key reasons. First, it is a straightforward and understandable framework (Hammond et al. 2002, Baker et al. 2022), which was essential given capacity and timing constraints. Second, the PrOACT framework has been applied widely in natural resources management in the past, thus providing previous case studies upon which we could draw for methods (Marcot et al. 2012, Chambers et al. 2019, Runge et al. 2020, Hemming et al. 2022). Third, the PrOACT model is taught in internal U.S. Forest Service training on risk management and decision making so there is consistency in use of the framework and a longer horizon with similar approaches going back well over a decade to the Eastern Forest Threat Assessment Center's use of the Comparative Risk Assessment Framework and Tools framework (U.S. Forest Service 2023). The team subsequently participated in a workshop with decision makers (February 12, 2021) to formally define the problem and to clarify the decision makers' objectives. After the meeting with decision makers, the team analyzed the consequences of the alternatives and developed an integer program to quantify trade-offs between competing objectives. The results of this analysis were provided to decision makers at a trade-off analysis workshop (June 14, 2021), where decision makers met to discuss and assess the alternatives and to decide on the path forward. The decision was announced on October 27, 2021 and comments on the decision were solicited from stakeholders. After reviewing the comments, the RMA-FEC published a final phase 1 decision on January 10, 2022. As of this writing, the second phase is underway, with a target implementation date of December 31, 2024.

Problem Statement

When we joined the Decision Efficiency Team, we perceived two main challenges regarding the definition of the problem. The first, finding common ground in a multiagency context where agencies have a wide variety of organization missions and capabilities and thus getting decision makers aligned on the problem to be solved (as well as the objectives), is routinely encountered in multiagency contexts (Gregory 2012, Marcot et al. 2012, Runge et al. 2015, Martin et al. 2019) and can be quite challenging to overcome. However, in this case, we found agency representatives had a fundamental agreement on the problem that needed to be solved. The second challenge, the lack of clarity that had resulted in stakeholder confusion, proved to be more time consuming to overcome. Having an ill-defined problem is a well-recognized issue in the decision analysis literature (Keeney 2004, Gregory 2012, Game et al. 2013); thus, in our initial role on the team, it was not surprising to find that problem definition lay at the root of the challenges.

The original problem statement guiding the project was developed in late 2019 by the original team members. It was relatively short, comprised of four sentences, and focused almost entirely on the recruitment and retention issues that sparked the project. The statement is as follows (Pechota 2019):

> The Rocky Mountain Coordinating Group has recognize a significant problem with recruiting and retaining employees to perform the dispatch function. In order to address this problem, a detailed dispatch consolidation and efficiency study has been chartered. This study will attempt to model a range of alternative based on the RMCG approved seven analysis criteria. The criteria will be applied consistently across all alternatives being considered.

Although both the team and the decision makers initially agreed that this was an accurate problem statement, it was not comprehensive enough to allay confusion among stakeholders about the goals of the project. As stated above, there were two main camps of stakeholders: those who thought the purpose of the project was narrowly limited to recruitment and retention, and other stakeholders who viewed the challenges of recruitment and retention as symptomatic of broader systemic issues that warranted resolving. The decision makers unanimously agreed with the latter group of stakeholders that the goal of the project was to resolve the systematic issues that were impacting recruitment and retention and, further, that there were additional hindrances to providing a high-quality dispatching service that should also be addressed during the project. Therefore, the team facilitated a workshop with the decision makers to develop a comprehensive problem statement to articulate the challenges facing the current dispatching system more clearly.

The problem definition section of the workshop was built around the questions outlined in Hemming et al. (2022, table 3), with some questions slightly altered to specifically address the dispatching system (e.g., "Where do you see the dispatch program as a strategic element of the current fire management program in Colorado?"). Because the workshop took place during the COVID-19 pandemic, it took place virtually. A shared screen and whiteboard tool were used to record answers to the problem framing questions. During the workshop, decision makers identified all the limitations they had observed within the current dispatching system and articulated how these limitations specifically impacted the dispatching system. After the workshop, the team drafted a formally written problem statement reflecting the results of the workshop which was sent to decision makers for review. Their comments were incorporated into the document and a final problem statement was then approved by the decision makers. An excerpt from the final problem statement is as follows (Belval et al. 2021):

> The demand for dispatching services in Colorado has increased substantially since the current dispatching system was designed 40 years ago and this demand is expected to continue to grow. The current dispatching system is not built to accommodate these needs: there are limitations on the current center buildings and infrastructure in addition to challenges with staffing that have created inefficiencies within the dispatching work environment. In addition to the increase in the demand for dispatching services, changes to assigned roles and responsibilities have led to expectations that dispatchers will provide services beyond the core dispatching duties. Challenges with recruitment and retention have exacerbated the increase in dispatcher responsibilities as mission critical tasks must be spread across fewer employees. Variation in standard practices across dispatching centers has also led to challenges for resources as they move between centers. While high levels of dispatching service have generally been maintained despite these challenges, additional stress on the system is likely to lead to lowered levels of customer service, including delays in mobilization of resources and inefficient management and tracking of resources in the field.
>
> The RMCG and RMA-FEC would like to provide a resilient dispatching system that can adapt to the expected stresses of future fire seasons while providing a high quality and consistent level of customer service in a cost-effective manner. They aim to do so by addressing and resolving systemic issues that lead to inefficiencies. Specifically, they want to eliminate the limitations imposed by office layout and space and technological capabilities, reduce staffing issues by better providing for the well-being of employees, and improve standardization across the system. To achieve these goals, RMCG and RMA-FEC are considering a reorganization of Colorado's dispatching system, which may include changes to the dispatching zone boundaries, the number and location of dispatching centers throughout the state, the organization of the staffing of the dispatching centers, the design of the centers themselves (space available, office layout and investments in technological tools), and standardization of operating procedures. The state of Kansas will also be affected, as Kansas resources are dispatched through a center located in Colorado.

Not only did the new problem statement address the issues that were causing recruitment and retention, but it also spoke to the decision makers' vision for the final project outcome: "a resilient dispatching system that can adapt to the expected stresses of future fire seasons while providing a high quality and consistent level of customer service in a cost-effective manner."

The new problem statement included six additional sections that are not shown in Text Box 2. Five of these sections detailed the specific administrative and social problems that decision makers had observed in the current dispatching system. For example, one section focused on the layout and available office space in dispatch centers, which decision makers found insufficient to support communication and coordination between dispatchers. Another section focused on limitations with current center communication infrastructure and interoperability. Three other sections addressed standardization of operating procedures and dispatcher responsibilities, staffing of dispatching centers, and cost.

The problem statement also included a section directly addressing the interconnectedness between decision types, which was a critical facet of this problem, and a characteristic that can lead to suboptimal decisions (Gregory 2012). Decision makers had identified three key phase 1 decisions: the dispatching zone boundaries, the cities in which dispatching centers would be located, and center ownership (i.e., whether the land and building would be agency owned or leased). Initially, these decisions were being considered separately. However, these decisions were highly interconnected. The number of centers is a direct outcome of the dispatch zone boundaries, and as the dispatching centers must be located within their dispatching zones, the location of the centers is also affected by zone boundaries. The location of the centers will affect the initial center setup cost as the build/leasing costs vary between cities. Although build/lease should theoretically be included in these phase 1 decisions, 10-year leasing costs ended up being always less than building costs in all cities where leasing was feasible; therefore, we do not address that decision further in this paper. Center locations will also affect annual staffing costs, as some of the cities under consideration lie in different cost-of-living adjustment zones. The staffing configuration at each center will be affected by the number of centers; overall numbers of staff could vary substantially between alternatives to provide the redundancy needed to eliminate current understaffing. Thus, the annual cost of staffing across the system may be highly impacted by the combination of the number of centers and the associated staffing configuration and the locations of these centers. Standardization of procedures (a phase 2 decision) may also be affected by the number of centers: fewer centers inherently provide fewer opportunities for variations to arise. Given the high levels of interconnectedness between decisions, decision makers agreed that outcomes of these three phase 1 decisions would need to be considered jointly.

Objectives

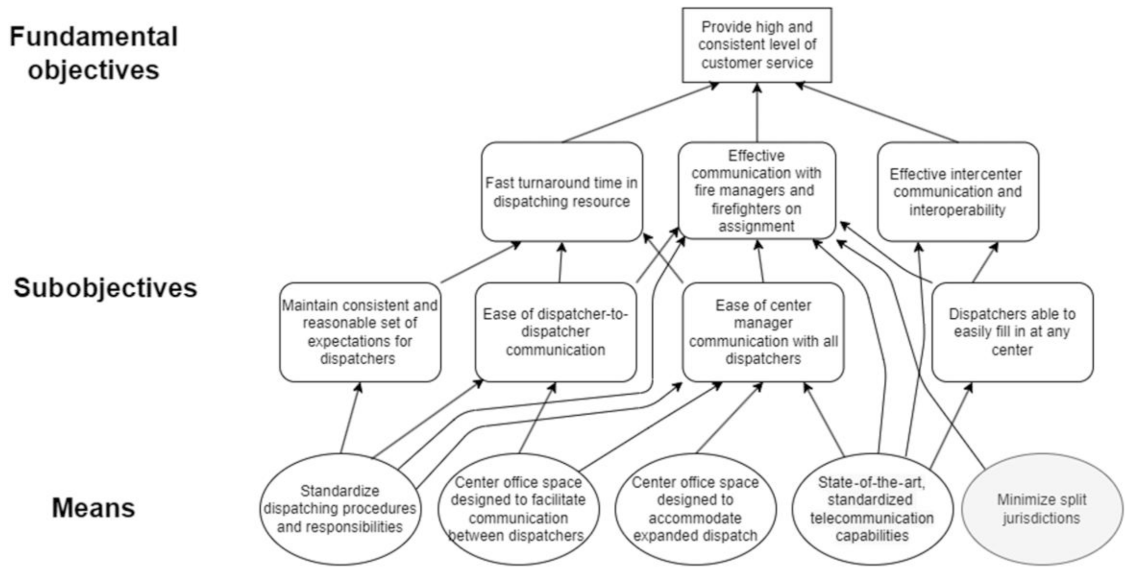
As with the problem statement, decision makers were in relatively high alignment regarding the objectives of the project, though articulation of fundamental objectives and the means to achieve them needed additional clarity. During the workshop in which decision makers articulated the problems facing the dispatching system, decision makers also developed objectives hierarchies: these diagrams link the fundamental objectives of the project to the means by which the objectives may be achieved (Gregory 2012). Because the workshop was virtual, the discussion of objectives was aided by whiteboarding software shared on the facilitators screen, and the initial objective hierarchy diagram was built with decision makers directing the addition objectives and means to the diagram. During the analysis of the workshop content, we grouped fundamental objectives into four main categories: (1) providing high and consistent levels of customer service, (2) resiliency and adaptability of the system to current and future needs, (3) providing for the health and well-being of employees, and (4) stewarding taxpayer dollars wisely. Each of these fundamental objectives is examined in detail below, identifying subobjectives that are critical parts of the objectives and the means by which the objectives and subobjectives can be achieved. The interdependencies and overlap between objectives result in some subobjectives and means appearing in more than one section. The team iterated on the grouping of fundamental objectives and their linkages with subobjectives and means, then results were provided to decision makers via email. Because of their high level of involvement in the initial development and some of the team members' expertise in dispatching, very few minor changes were requested.

High levels of customer service at a dispatch centers are primarily defined by fast turnaround times when mobilizing resources, effective communications with firefighters on assignment, and effective communication with other dispatching centers (Figure 1). In order to achieve these goals, dispatchers need standardized dispatching procedures and responsibilities that are consistent across positions at each center, center office space that is designed to facilitate communication between dispatchers and to accommodate "expanded dispatch," state-of-the-art telecommunication capabilities, and a minimum number of jurisdictions that are split between dispatching centers.

A dispatching system that is resilient and adaptable to future needs must provide for effective intercenter communication and interoperability, good relationships and communication with partners, and an adaptable workforce that can achieve the work needed (Figure 2). Intercenter communication and interoperability are facilitated by state-of-the-art, standardized telecommunication capabilities and standardized procedures and responsibilities that allow dispatchers to easily move between centers. Strong and effective communication with partners requires a staff empowered to nurture relationships (i.e., staff with a reasonable, clearly defined set of expectations), as well as technological capabilities. Maintaining consistent and reasonable expectations for dispatchers ensures that they can adapt to changing circumstances. Consistent and reasonable expectations can be provided through standardization of responsibilities, adequate staffing redundancy (which may include hiring more dispatchers than are currently employed), and the balancing workloads across staff and centers.

The goal of providing for the health and well-being of employees (Figure 3) is consistent with several agencies' initiatives (e.g., the U.S. Forest Service created the Work Environment and Performance Office in September 2018), and it contributes to other fundamental goals of providing high levels of customer service and providing a resilient and adaptable system, as understaffing has been identified as a key issue with which the current dispatching system struggles. Adequate staffing redundancy regarding dispatching qualifications at each dispatch center is critical to ensuring employees are not overworked and are able to take time off as well as attend professional development opportunities. A more balanced workload across the dispatching staff within the system would also facilitate these goals. New position descriptions for center managers of large and complex centers would also provide additional professional opportunities within the dispatching community. Recruitment and retention of staff is affected by both the professional development opportunities and the maintenance of a consistent and reasonable set of expectations for dispatchers. In addition,

Figure 1. The Subobjectives and Means Associated with the Fundamental Objective of Providing High and Consistent Levels of Customer Service



locating centers in desirable cities is expected to contribute to recruitment and retention efforts.

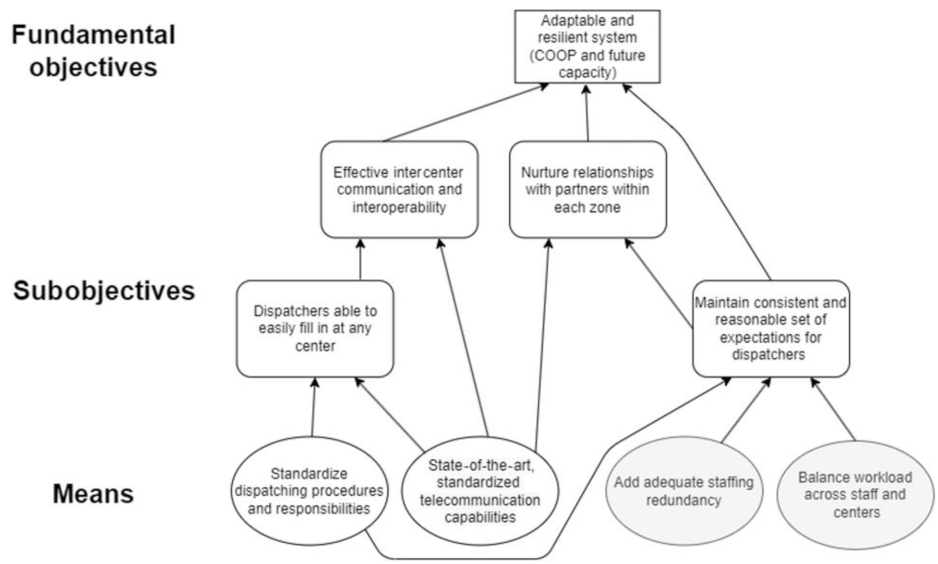
Stewarding taxpayer dollars wisely (Figure 4) was an important consideration, as all of the agencies involved are funded through tax dollars, and proposed changes do have associated costs. To ensure careful investment of these resources, examining the redistribution of long-term organizational costs such as leasing, maintenance, and staffing costs is important. In addition, considering the short-term costs of reorganizing the system is also important, for example, construction, leasing, and technology acquisition costs.

Alternatives

Candidate zones were established on the basis of major geographic and jurisdictional features (e.g., continental divide, interstates, national forests, counties), and candidate center locations on the basis of cities initially judged to have sufficient population and capacity (particularly internet connectivity). Stakeholders were highly involved in alternative development, with multiple workshops being held to solicit their input throughout the development process, including an initial set of workshops to capture ideas from a broad array of those impacted, and follow up workshops to assess the set of alternatives that were developed. The team worked to include a wide variety of alternatives, some of which were outside the initial comfort zone of stakeholders (e.g., two zones) and decision makers (e.g., six zones). The status quo alternative was clear in this case (six zones with centers located in the current city). A wide variety of cities were considered, from large urban areas (e.g., Denver metro area) to smaller, rural communities (e.g., Meeker and Rifle). The alternative development process aligned closely with Gregory (2012), though at that point in the process, no experts in decision analysis were involved in the project.

Despite the alternative development occurring prior to clear articulation of the problem statement and objectives, the high level of stakeholder involvement, the thoughtful and thorough iterative process engaged in by the team, the high levels of expertise on the team, and the high levels of agreement among decision makers regarding the problem and objectives led to alternatives that did not need any changes once the problem and objectives were more clearly defined. Rather than changing the alternatives, the clearer problem definition and objective clarification allowed for a more nuanced accounting of consequences and trade-off analysis, which are discussed in later sections of this paper.

Figure 2. The Subobjectives and Means Associated with the Fundamental Objective of Fostering Resiliency and Adaptability of the System to Current and Future Needs



The alternatives prepared for the phase 1 decisions included four candidate sets of dispatch zone boundaries, 11 candidate cities for dispatch center location, and two options for building ownership. One alternative set of zone boundaries was the same as historical zone boundaries: this would result no change in the current zone boundaries in Colorado (six zones total; see Figure 5). Were this option to be adopted, decision makers had already decided not to change the cities in which dispatch centers were located. In addition to the status quo,

Figure 3. The Subobjectives and Means Associated with the Fundamental Objective of Providing for the Health and Well-Being of Employees

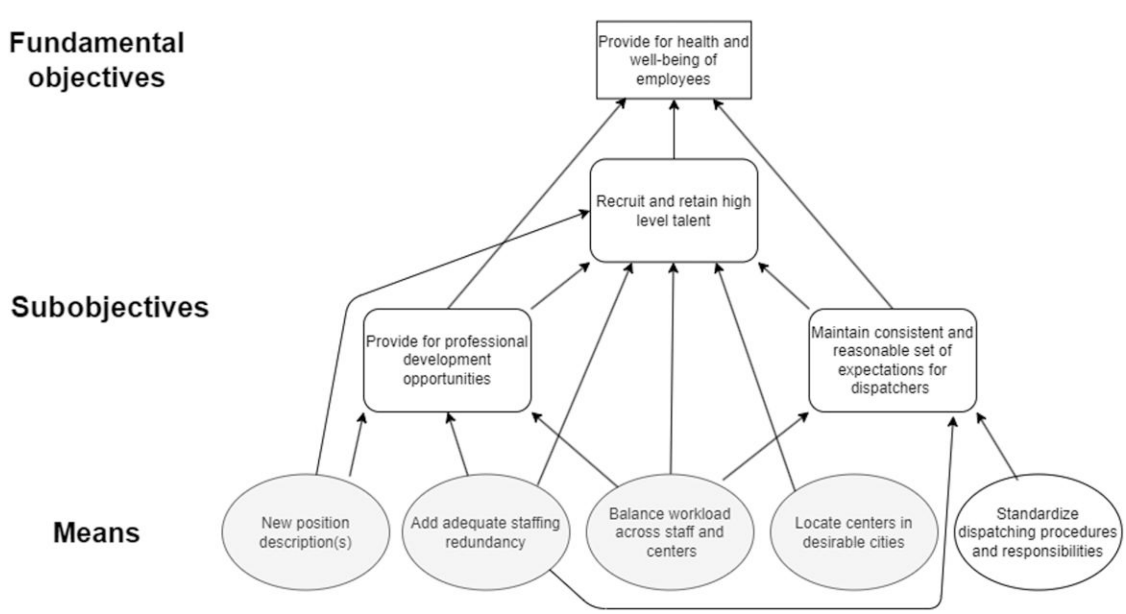
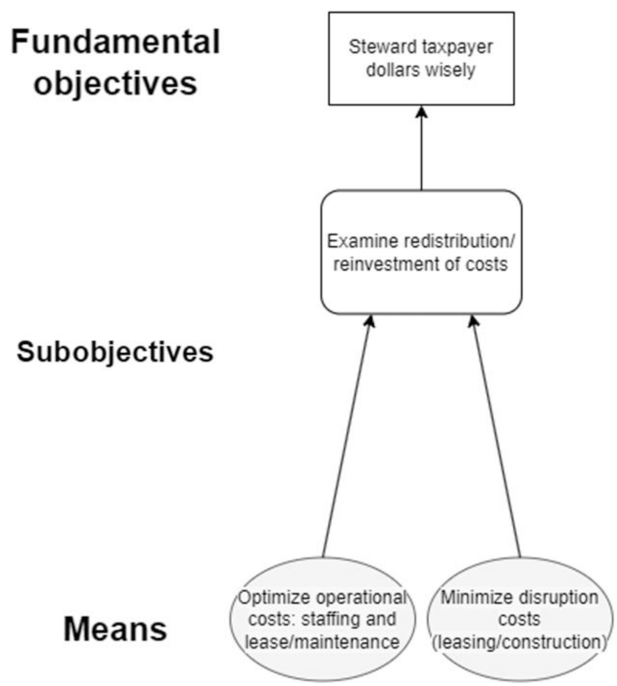


Figure 4. The Subobjectives and Means Associated with the Fundamental Objective of Stewarding Taxpayer Dollars Wisely



there was an alternative that had four zones, an alternative that had three zones, and an alternative that had two zones. Because there were 11 options for cities in which to locate dispatching centers (Montrose, Craig, Durango, Grand Junction, Delta, Meeker, Rifle, Fort Collins, Pueblo, Denver Metro, and Colorado Springs), the combination of zone boundaries and dispatching center locations resulted in hundreds of feasible alternatives; thus, enumeration of all possible combinations of center locations and zones was not fruitful. Instead, decision makers chose to use an integer program to prune the broader set of all possible alternatives (described in the trade-offs section).

Consequences

Candidate evaluation attributes were assessed to reflect the means identified by decision makers in the objectives hierarchies. The attributes were initially developed by the displacing experts on the Decision Efficiency Team and were then iteratively refined by communicating with the decision makers. Although most attribute selection occurred prior to our entry on the team, when we assessed the means and attributes associated with them, we found the selected attributes generally had the qualities of "good" attributes: they were unambiguous, comprehensive, direct, operational, and understandable (Keeney and Gregory 2005). Some of these means were easily represented with natural attributes (e.g., using cost of living to indicate the desirability of a city), whereas others required proxies or constructed attributes that were developed by trusted experts specifically to support this type of decision (e.g., weighted measures of workload were designed by the Interagency Dispatch Working Group). There were 10 key attributes developed to reflect the means that were associated with phase 1 decisions. These attributes were linked to the objective they reflected as well as the specific decision that impacted them. Table 2 lists the final set of evaluation attributes used to evaluate the alternatives, the means and fundamental objectives to which the evaluation metric is linked, and which of the three decision types impacts the attribute. Some attributes reflected more than one fundamental objective.

The two attributes to reflect annual dispatching workload (both center and dispatcher level) are a weighted combination of subattributes that reflect the core dispatching duties as defined by the Interagency Dispatch Implementation Project. These subattributes reflect time spent on response to fire activity as well as other resource tracking activities. Although these attributes are constructed and are less understandable than ideal, they were developed by experts in the field specifically to reflect relative workloads of dispatching centers for use in multiple other decision processes and have broad support and agreement that they do reflect workload well. The staffing redundancy metric was a proxy produced by expert judgment; experts ranked organizational staffing configurations from one to five to reflect relative staffing levels between organizations and explicitly considered increased flexibility for dispatchers as centers get larger and there are more dispatching positions within the same center. Cost of living was an aggregated metric that included the cost of groceries, healthcare, housing, utilities, and transportation. City desirability was a proxy constructed using a survey of dispatchers from 2018 that asked respondents to list cities in which they would apply for a job. The number of counties spilt by zone boundaries was a natural attribute that reflected the

Figure 5. (Color online) The Original Six Dispatching Zone Boundaries in Colorado

number of counties that would need to work with more than one dispatching center, increasing overhead work and increasing the number of working relationships needed to efficiently respond to wildland fires. Similarly, the number of federal management units split by zone boundaries indicated the number of federal management units that would need to work with more than one dispatching center. Annual organizational salary cost estimates were natural attributes that were calculated based upon the required organization needed to respond to workload in each proposed zone and reflected the government cost of living adjustment areas in which each city was located. Costs to build a new center, as well as costs associated with leasing and retrofitting a center, in each city over a 10-year period were natural attributes and were calculated by a U.S. Forest Service realty specialist and a U.S. Forest Service engineer.

Trade-Off Analysis

The Decision Efficiency Team built an IP (Wolsey 2021) to facilitate an initial trade-off analysis between the many combinations of zone boundaries, center locations, and building ownership. This IP modeled the three phase 1 decisions: the zone configuration, which cities to locate the centers in, and whether to lease or build the center in each city (the IP was designed prior to discovering that leasing was always less expensive, so it did initially include center ownership). For the IP notation, n is used to index zones configuration, s to index individual zones within each configuration, l to index cities, and b to index building options. The set of possible zone configurations is given by $n \in \Omega$ (here, $\Omega = \{2, 3, 4, 6\}$). The set of all zones in zone configuration n is given by $s \in T_n$; for example, $T_4 = \{1, 2, 3, 4\}$. The set of all possible center locations is given by $l \in \Theta$, and the set of cities associated with zone s in zone configuration n is given by $c \in \Gamma_{n,s}$; for example, in the zone configuration with three zones, there are three cities that could accommodate a center in the first zone, which is given by $\Gamma_{3,1} = \{\text{Fort Collins, Craig, Meeker}\}$. The set of building options is given by $b \in \beta$. For this problem, $\beta = \{\text{build, lease}\}$.

Because the three decisions are interconnected, our set of decision variables must include one for each combination of decisions. Thus, the decision variables are binary and defined as $X_{n,l,b}$, which takes a value of one when n zones are chosen with one of the centers in city l built using construction option b. We also include binary state variables to simplify the objective function and constraints: Z_n, which takes a value of one if the n zone configuration is chosen, and C_l, which takes a value of one if city l is chosen as the location for a center location.

Constraints were developed to ensure the IP chose only one zone configuration option (Equation 1) and that the IP chose the same number of cities as zones in the chosen zone configuration (Equation 2). In addition, for each zone–city pair, the IP can choose only to either build or lease and must do neither unless that particular city is picked as the center location for that zone (Equation 3). Another set of constraints forces the IP to choose to either build or lease if we have chosen that city and that zone configuration (Equation 4). The last set of constraints requires that we must pick one city to locate the

Table 2. The Final Set of Evaluation Attributes Used to Evaluate the Alternatives

Attribute name	Associated mean(s)	Associated fundamental objective(s)	Associated decision(s)
Workload per dispatching center	Balance workload across staff and centers	Provide for health and well-being of employees, adaptable and resilient system	Zone boundaries
Maximum workload per dispatcher	Add adequate staffing redundancy	Provide for health and well-being of employees, adaptable and resilient system	Zone boundaries
Staffing redundancy	Add adequate staffing redundancy	Provide for health and well-being of employees, adaptable and resilient system	Zone boundaries
Cost of living	Locate centers in desirable cities	Provide for health and well-being of employees	Zone boundaries and subsequent center location
City desirability	Locate centers in desirable cities	Provide for health and well-being of employees	Zone boundaries and subsequent center locations
Number counties split by zone boundaries	Minimize split jurisdictions	Provide high and consistent levels of customer service	Zone boundaries
Number federal management units split by zone boundaries	Minimize split jurisdictions	Provide high and consistent levels of customer service	Zone boundaries
Annual organizational salary costs	Optimize operational costs	Steward taxpayer dollars wisely	Zone boundaries and subsequent center locations
Cost to build center	Minimize disruption costs	Steward taxpayer dollars wisely	Center locations and center ownership
Cost to lease and retrofit center	Minimize disruption costs	Steward taxpayer dollars wisely	Center locations and center ownership

center in for each zone in the chosen zone configuration (Equation 5):

$$\sum_{n\in\Omega} Z_n = 1, \tag{1}$$

$$\sum_{l\in\Theta} C_l = \sum_{n\in\Omega} n * Z_n, \tag{2}$$

$$\sum_{b\in\beta} X_{n,l,b} \le \frac{1}{2}(C_l + Z_n) \qquad \forall n \in \Omega,\ l \in \Theta, \tag{3}$$

$$\sum_{b\in\beta} X_{n,l,b} \ge 1 - M(2 - C_l - Z_n) \qquad \forall n \in \Omega,\ l\ in\ \Theta. \tag{4}$$

$$\sum_{c\in\Gamma_{n,s},\, b\in\beta} X_{n,c,b} = Z_n \qquad \forall n \in \Omega,\ s \in \mathrm{T}_n. \tag{5}$$

The attributes identified in the consequences phase of the decision process were incorporated in the IP within the objective function. The team noted that the attributes fit into four main categories: the metric was linked directly to either cost (cost to build or lease the center in city l, $d_{b,l}$, and the organizational cost of the center for each zone if the center was located within city l, $o_{n,l}$), location desirability for dispatching personnel (cost of living, col_l, and survey desirability sd_l), split jurisdictions (the number of split county jurisdictions, sc_n, and the number of split federal jurisdictions, sf_n), or workload for dispatchers (the maximum workload on any dispatcher across the entire organization given a chosen zone configuration, mw_n, the variation between the minimum and maximum dispatcher workload given a chosen zone configuration, vw_n, and the systemic redundancy allowing dispatchers higher work–life balance, r_n). In order to remove any effects of double counting (Edwards et al. 2007) and to adequately compare attributes using different units, the attributes were normalized and then weighted by a "within category" weight (see the bottom set of weights in Figure 6) and a "category weight" (see the top set of weights in Figure 6) associated with the weight assigned to cost, location desirability, split jurisdictions, and workload, resulting in a unique weight for each metric on each run. We denote these weights by $\{w_1, w_2, \ldots, w_9\}$ in Equation (6). The team systematically varied weights over 10,000 model runs to identify solutions along the efficient frontier (cite efficient frontier) and tracked the persistence of each optimal solution across this set of Pareto-optimal solutions produced by the combinations of weights:

$$
\begin{aligned}
Min \sum_{n\in\Omega} &(w_1 * sc_n + w_2 * sf_n + w_3 * mw_n \\
&+ w_4 * vw_n + w_5 * r_n) * Z_n \\
+ \sum_{n\in \Omega, l\in\Gamma_{n,s}, b\in\beta} &\frac{1}{n}(w_6 * col_l + w_7 * sd_l) \\
&+ (w_8 * d_{b,l} + w_9 * o_{n,l}) * X_{n,l,b}.
\end{aligned} \tag{6}
$$

The final IP formulation for this specific problem resulted in a total of 78 decision variables, four zone configuration state variables, and 11 center location state variables. There were a total of 95 constraints. This is a relatively small IP that can be quickly solved (less than one second per run) using the PuLP library (Mitchell et al. 2011) with Cbc as the optimizer (johnjforrest et al. 2020) implemented in Python using a script run by Google Colab. Google Colab was chosen for implementation for ease of sharing the script with multiple users who may not have Python on their computers. Although computing resources and limits while using Google Colab may vary, we never had issues with computing power or solution times.

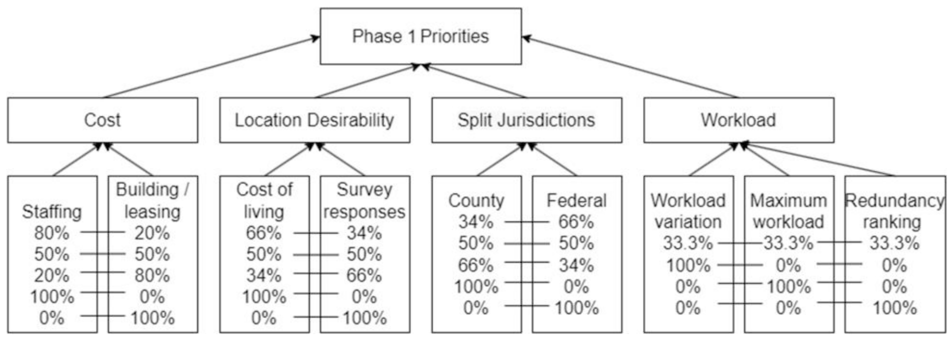
Across all the runs, only 13 unique combinations of decisions were ever chosen, indicating that many of the combinations of zone boundaries, center locations, and building ownership were clearly dominated (Liesiö et al. 2007, Luc 2008) by other solutions when considering the set of attributes developed for alternative assessment under the set of weights chosen. The team choose the six most persistent of these nondominated solutions as the "initial efficient solutions" that were presented to decision makers to begin the trade-off workshop. This set of solutions did not include any alternatives that chose six zones or four zones. However, because these options might be preferred by decision makers after discussing uncertainty and factors that the team could not include in the IP, the team chose to add the six-zone solution as well as a solution with four zones to the set of initial efficient alternatives.

The team prepared a variety of visual tools to allow decision makers to compare between alternatives, including bar charts showing how different sets of zone boundaries and different cities performed using the selected attributes as well as radar charts to compare the selected set of nondominated solutions across all attributes (Figure 7). Although the radar charts do not allow for managers to see the absolute value of the objectives, they do provide a valuable visualization of the attributes in which each alternative did and did not dominate and where the alternative ranks in each attribute in comparison with the entire set of alternatives. The bar charts were provided to allow decision makers to see the differences between how alternatives performed by absolute attribute value.

During their discussions in the trade-off analysis workshop, it emerged that the representatives saw the objectives as fitting into two main classes: objectives regarding the well-being of employees (workload distribution and location desirability) and organizational objectives (split jurisdictions and costs). All representatives expressed a clear preference to maximize the well-being of employees ahead of maximizing the organizational objectives.

With the help of the visualizations, which provoked a nuanced discussion of the attributes, how alternatives performed, and how the attributes contributed to fundamental objectives, representatives confirmed that the key objectives for the decision to reorganize the dispatching centers in Colorado were generally well represented by the quantitative attributes included in the IP. There were four additional considerations added to the eight original attributes at the final trade-off analysis meeting: (1) approval of a new position description for a manager of a larger dispatching center, (2) future anticipated workload (fire activity, additional resources and demographic change), (3) occurrence and duration of extended dispatch, and (4) additional continuity of operations planning (COOP) considerations. The first three of these were explicitly connected to the means objectives identified in the objectives hierarchies and either could not be included in the IP because of high levels of uncertainty (1) or their explicit consideration of uncertainty around attributes already developed ((2) and (3)). The fourth consideration was not initially included in the means objectives, but came up as an oversight when decision makers were discussing the pros and cons of the number of centers and should have

Figure 6. The Alternative Weights used to Create the Weighted Combination of All of the Objectives

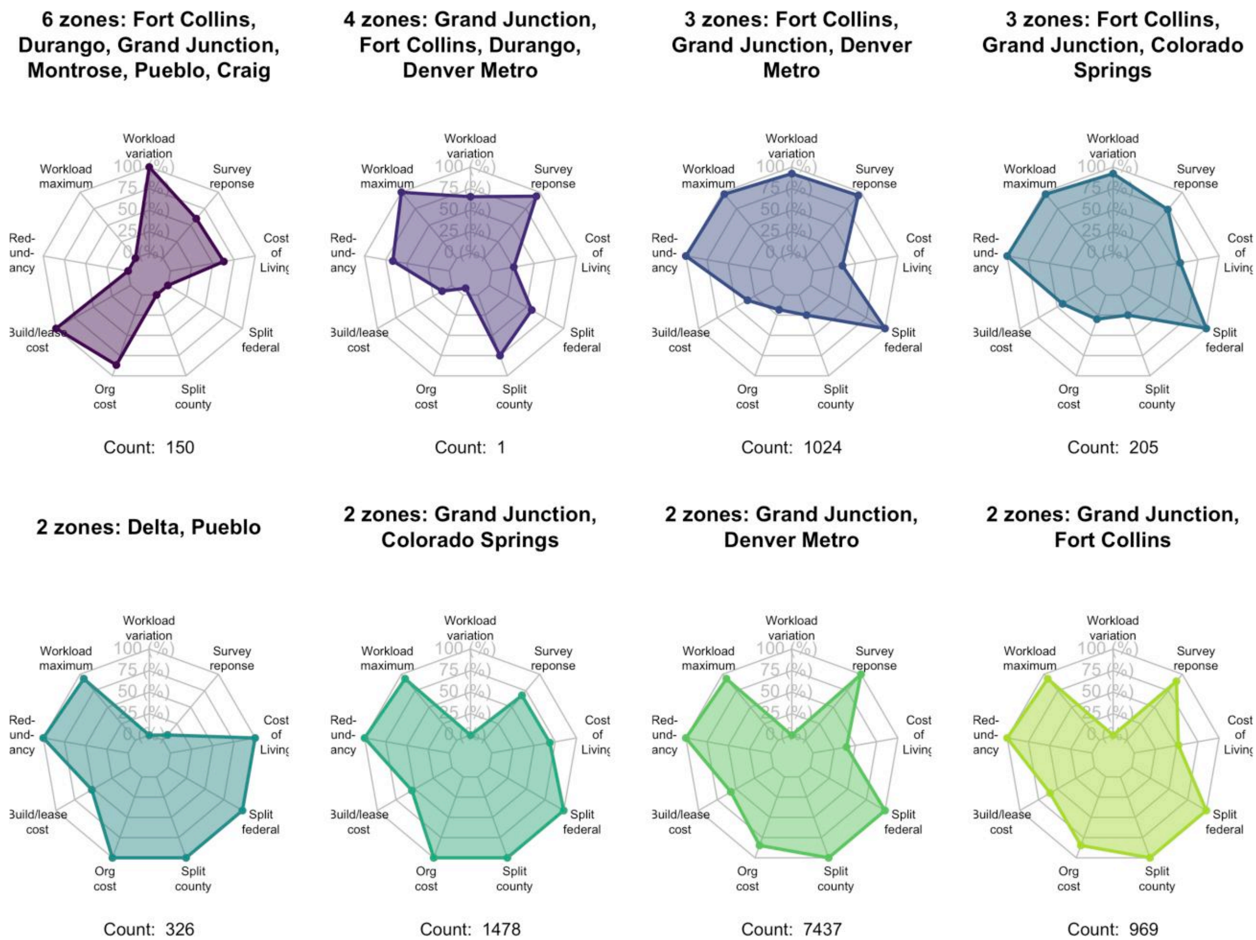


been a means objective under "providing high levels of customer service." Although the addition of new metrics would typically impact the set of nondominated solutions, requiring optimization model reruns, these new considerations impacted only a single decision type and did not have clear attributes that could be associated with them; thus, the new considerations were added to the ranking table, but were never incorporated into the optimization model. Additionally, the IP was developed specifically to winnow the hundreds of potential solutions down to a handful that scored highly on the selected attributes. We knew that additional information, considerations, and uncertainty would be integrated into the final ranking table and decisions, and that the initial set of nondominated solutions might be changed as decision makers filled out a consequences and ranking chart.

After an initial discussion, the decision makers developed a consequences and ranking table that explicitly considered the impact of the attribute performance on their fundamental objectives, as well as potential mitigations that could be taken in phase 2 to minimize detrimental impacts for six alternatives. The table allowed decision makers to both describe the impacts of the alternative on the attribute and to allow them to rank the impacts relative to other alternatives. Four of these alternatives came directly from the initial set of nondominated solutions that were provided by the IP, whereas two of these alternatives that were included in the consequences and ranking table were not in the set of nondominated solutions. Specifically, decision makers decided to change a few of the cities based upon their assessment of desirability and cost of living trade-offs; they noted that the survey producing the desirability attribute was three years old, and the cost of living in some cities had changed substantially in that time period. The radar charts served as a starting point for discussion regarding how each alternative performed with regard to the 12 key factors (variation in workload between centers, maximum workload per employee, position redundancy, reliance on an approved federal GS-12 position (U.S. Office of Personnel Management 2009) description, future anticipated workload across zones, cost of living in each city, survey responses indicating city desirability, number of split federal jurisdictions, number of split county jurisdiction, annual organizational costs, build/lease costs, COOP, and the likely duration of expanded dispatch for each zone). For each factor, each alternative was evaluated to determine whether the alternative's effect on that factor was negative, negligible, or positive, particularly with regard to how the alternatives compared with each other. Representatives discussed how information not included in the quantitative attributes and mitigations might affect each alternatives score for each factor. The ranking and consequences table was used to facilitate discussion and final decisions regarding the rank of each alternative in each metric.

The decision makers found that the three-zone alternatives generally performed well and ranked highly in the objectives they considered most important. Although the two-zone options were initially appealing based upon the rankings of alternatives across factors, there were substantial transactional and implementation costs associated with these options that may not have been well represented in the factors considered, or the factors were

Figure 7. (Color online) Radar Charts for Each Initial Efficient Alternative



Note. For each point in a plot, the closer it is to the edge of the "web," the better that alternative performed for that objective.

important enough that they outweighed other considerations. For example, the failure to obtain approval for a center manager position description for the larger centers made the two-zone option infeasible, and approval of such a position description cannot be guaranteed. In addition, the organizational changes required to move from a six-zone current configuration to a two-zone configuration was determined to be quite substantial, particularly with regard to current culture, multiagency relationships, multiagency operating procedures, and the transition of the workforce. The four-zone alternatives were eliminated because of underperformance in objectives regarding the well-being of employees as well as high organizational costs. Thus, the three-zone alternatives were found to provide a reasonable middle ground between the efficiencies provided by the two-zone alternatives and the lower transactional and implementation costs provided by the six- and four-zone options. To balance the trade-off between cost of living and expressed city desirability, representatives decided to recommend that Grand Junction, Fort Collins, and Colorado Springs be considered for center locations. Specifically, the final decision read (Loach 2022):

> After careful consideration and multiple stakeholder meetings, the Rocky Mountain Area Fire Executive Council has decided to move forward with the three-zone alternative for wildland dispatch centers in Colorado and Kansas. This alternative best meets the desired objectives and is a balance between the efficiencies provided by the two-zone alternatives and the lower transactional and implementation costs

provided by the six and four zone alternatives. The three center locations will be in Grand Junction, Fort Collins, and Colorado Springs.

This particular alternative was, in fact, one of the initial nondominated solutions found by the IP.

Discussion

The need for a resilient and adaptable dispatching system is driven by ecological and social processes (wildland fire occurrence and the subsequent threats to communities and ecosystems), but the system itself is constrained by administrative and social concerns (e.g., recruitment and retention of dispatchers and office space and technology limitations). This system is an example of decision, utility, and ecological thresholds interacting (Martin et al. 2009). In this case, fire activity creates the ecological set of thresholds; that is, fire activity is increasing, which, compounded with increasing human presence on the landscape, threatens more values. The utility threshold is determined by the desired response capacity needed to adequately respond to the increased fire activity. These result in the decision thresholds driving decision makers to determine how many and where to place dispatching centers. Applying and adapting multiple techniques developed within a structured decision-making framework including multiattribute optimization allowed us to help decision makers effectively and efficiently work through this complex decision. The PrOACT model (Hammond et al. 2002) principally helped frame the decision process, whereas objectives hierarchies, integer programming, visualization techniques, and trade-off matrices provided support during different phases of the process and helped to clarify decisions whose outcomes will be determined, in part, by an unpredictable set of processes (fire activity, demographic changes, and subsequent demand for fire suppression capacity).

Our experience underscored previous findings regarding how crucial it is to develop a problem statement that reflects the fundamental problems the decisions are meant to address (Gregory 2012, Marcot et al. 2012, Game et al. 2013). Even with relatively high levels of alignment between key interagency players regarding the problem and objectives, it was hard to dig beneath the surface to get beyond the symptom that initially drew decision makers' attention to the dispatching system (i.e., recruitment and retention) to bring to light the driving problems inherent within the dispatching system (e.g., workload imbalance, staffing of dispatch centers, limitations with current center communication infrastructure and interoperability, and standardization of operating procedures and dispatcher responsibilities). We also found a high value in revisiting the problem statement and objectives in later phases of the decision-making process to ensure alignment. There are additional methods in problem structuring that could be brought to bear from the beginning for future dispatch reorganization decisions. For example, Smith and Shaw (2019) define four pillars of problem structuring methods, some of which we explicitly addressed, and others that could use improvement in the future. For example, although we did not model the dispatch system to explicitly outline the system characteristics, members of the Decision Efficiency Team were intimately familiar with its function. The process did include knowledge and involvement of stakeholders by facilitating group sessions, and it aimed to build buy-in for politically feasible outcomes. The process also included the value of model building through providing multiple opportunities for stakeholder feedback, developing a robust set of attributes that reflected stakeholder concerns, and an IP formulation that could be applied to other locations outside of Colorado.

Visualization played a large role in various phases of the decision process. Working through how fundamental objectives were related to response attributes in a visual format helped organize decision makers' thinking around their goals for the project and provided a basis for later discussions around prioritization of objectives. Visualizations of efficient alternatives proved valuable in provoking a rich discussion around evaluation criteria, particularly in the discussion of administrative and workforce objectives. Visualization of the trade-offs across favored alternatives in multiple different ways (radar charts, bar charts, and consequences and ranking tables) added to decision makers' certainty and comfort with their final decision.

Iteration between both decision makers and stakeholders and the team played a valuable role over the entire course of the project. Early iteration between the team and stakeholders, while alternatives were being developed, led to a robust set of alternatives that covered a wide variety of future options for organization of the dispatching system. Later in the project, iteration between the team and decision makers led to alignment on the problem statement and objectives in advance of the final trade-off analysis workshop, which allowed the trade-off analysis workshop to run very smoothly and productively.

Winnowing down from the full set of alternatives to an initial efficient set of alternatives was also valuable. Having fewer alternatives to consider made it easier for decision makers to discuss uncertainties of many types in more concrete terms. The rich conversations and dialogue led decision makers to choose an alternative that was included in the nondominated set, but they were confident that it addressed key uncertainties as well as objectives that are harder to measure and quantify.

The decision framework and process presented here proved valuable in helping the RMCG and RMA-FEC arrive at a phase 1 decision to consolidate and reorganize the wildfire dispatching system in Colorado and may provide a model for similar future decisions. It is important to note that when we became involved in the project, it already had all four of the critical components in place as outlined by Boston and Bettinger (2001): decision makers who prioritized this project, explicit processes for stakeholder involvement (outside of decision makers), data gathered through a variety of sources, and technology to analyze the data. The organizational commitment was a critical component of this project: the RMA-FEC had two personnel detailed into positions for over a year to dedicate the majority of their time to work on the project. These two individuals were the primary point of contact, set up meetings, developed documentation, and gathered information. This capacity was critical to getting the project completed, especially as it was interrupted by the COVID-19 pandemic, when most federal employees had to move to remote work and decision makers' capacity was shifted to mitigating impacts of COVID-19 on wildland fire management.

The same recruitment and retention issues that sparked the Colorado reorganization are present elsewhere in the wider U.S. wildfire dispatching system. For example, the Bozeman Interagency Dispatching Center was closed on April 18, 2022, with officials citing recruitment issues as the main reason for the closure (Dore 2022), and transferring the entirety of the workload to another dispatching center. This work adds to a growing body of risk and decision analysis techniques informing real-world decisions that are ideally supporting a more efficient and effective wildfire management system (Thompson et al. 2019, Calkin et al. 2021, Greiner et al. 2021, Schultz et al. 2021).

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