Rapp *et al. Fire Ecology* (2026) 22:71
https://doi.org/10.1186/s42408-026-00484-6

Fire Ecology

REVIEW

Open Access

Wildfire decision support tools: barriers, facilitators, and future directions for effectiveness

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Abstract

Background Decision support tools (DSTs) play an important role in all stages of wildland fire management from pre-fire planning to post-fire recovery. Recent studies centering on how end users and practitioners use DSTs in the field have assessed the barriers, facilitators, and uses for a number of wildfire DSTs. However, comparatively little attention has been paid to evaluating wildfire DST effectiveness at improving decision quality. We turn to the larger natural resource management literature on decision support to argue an effective DST is one that improves decision quality through either decision-relevant information or decision structuring. To define decision quality and understand how wildfire DSTs may contribute to decision quality, we conduct a review of the qualitative social science literature on wildfire DSTs ($n = 13$, USA, Canada, and Australia) and supplement with relevant grey literature ($n = 14$, USA). We summarize barriers, facilitators, and uses.

Results We find that key barriers include communication failures, cultural barriers, landscape characteristics, and resource, capacity, and user issues. Key facilitators include prior awareness, cultural beliefs, formal training, interpersonal relationships and trust, sufficient resources and capacity, and user-friendliness. We find that practitioners use DSTs for both decision tasks (e.g., articulating objectives, assessing tradeoffs) and non-decision tasks (e.g., knowledge confirmation, documentation).

Conclusion We conclude by suggesting future research should more explicitly focus on DST effectiveness, and we provide examples of how to translate existing criteria of DST effectiveness to two wildfire DSTs: Risk Management Assistance (RMA) and the Incident Strategic Alignment Process (ISAP).

Keywords Decision quality, Decision support tool evaluation, Wildfire, Fire management, Usable science

Resumen

Antecedentes Las herramientas de soporte para la toma de decisiones (DSTs, de ahora en más), juegan un rol importante en todos los estadios de manejo del fuego, desde el planeamiento en el pre-fuego hasta la recuperación en el post-fuego. Estudios recientes se centraron en como los usuarios finales y los practicantes que usan las DSTs en el campo han determinado las barreras, facilitadores, y otros usos para un número determinado de DSTs. Sin embargo y comparativamente, muy poca atención se ha brindado para evaluar la efectividad de las DSTs en la mejora de la calidad de las decisiones. Hemos echado mano a la amplia literatura sobre el soporte de decisiones en el manejo de los

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recursos naturales para argüir sobre si una efectiva DSTs es aquella que mejora la calidad de las decisiones mediante decisiones basadas en la información relevante, o a través de decisiones ya estructuradas previamente. Para definir la calidad de la decisión y entender como las DSTs en manejo del fuego pueden contribuir a esa calidad en la decisión, condujimos una revisión de la literatura proveniente de las ciencias sociales basadas en las DSTs en incendios de vegetación ($n = 13$, de los EEUU, Canadá, y Australia), suplementada con literatura relevante pero "gris" ($n = 14$, EEUU). Resumimos las barreras, facilitadores y usos.

Resultados Encontramos barreras clave que incluyen fallas en la comunicación, barreras culturales, características del paisaje, y recursos, capacidades y otras cuestiones relacionadas con los usuarios. Los facilitadores clave incluyen la concientización previa, las creencias culturales, el entrenamiento formal, las relaciones y la confianza interpersonal, recursos y capacidad suficiente, y el uso amigable de los recursos. Encontramos que los practicantes usan DSTs para tareas que implican la toma de decisiones (i. e. la articulación de objetivos, la determinación de intercambios en la toma de decisiones) y tareas que no implican decisiones (i. e. el conocimiento, la confirmación y la documentación).

Conclusiones Concluimos sugiriendo que investigaciones futuras deberían enfocarse explícitamente en la efectividad de las DSTs, y proveímos de ejemplos de cómo trasladar los criterios existentes en la efectividad de las DSTs, a dos DSTs implicadas en incendios de vegetación: la Asistencia en el Manejo del Riesgo, y el Proceso de Alineación Estratégica de Incidentes (ISAP).

Background

Wildland fire decision support tools

Decision support tools (DSTs; also called decision support systems and decision aids) have long played important roles in wildland fire management (Cruz and Alexander 2010; Pacheco et al. 2015). DSTs are computer-based applications intended to improve decision quality through the provision of decision-relevant information and decision structuring (Wong-Parodi et al. 2020; Colavito 2021; O'Mara et al. 2024). DSTs may be used in all stages of decision-making from pre-fire planning to fire response to post-fire recovery, and can be used for a variety of tasks, such as information provision and decision documentation. The literature dedicated to organizing, evaluating, and understanding wildfire DSTs is relatively nascent, but it is worth noting a few recent studies that provide foundational overviews and reviews of wildfire DSTs using both qualitative and quantitative approaches (e.g., Pacheco et al. 2015; Colavito 2021; Vásquez et al. 2021; O'Mara et al. 2024). A number of older reviews have become outdated as the field progresses rapidly and are not included herein. One recent effort to systematically categorize and evaluate wildfire DSTs was conducted by O'Mara et al. (2024). This study used a systematic literature review of peer-reviewed academic articles about wildfire DSTs, coded the relevant studies for eight application metrics, and then further examined individual tools to evaluate their similarities and differences using non-metric multidimensional scaling. O'Mara et al. (2024) then categorized wildfire DSTs into the following, non-discrete groups: fire behavior models, management frameworks, forest landscape models, post-fire modeling tools, wildfire risk models, and treatment prioritization tools. This combination of qualitative and quantitative methods allowed O'Mara et al. (2024) to make the case that many wildfire DSTs are difficult to use in collaborative decision-making and that field use of wildfire DSTs and the description of wildfire DSTs in the literature are often not aligned. This ultimately begs the question of how to better evaluate and understand tool use to ensure effective end user outcomes, as well as provide input to DST analysts for developing effective tools.

Further, as wildland fire DSTs become more common, there is interest in evaluating and understanding how they are used in the field by practitioners. Evaluating DST use in the field can involve assessing what encourages or discourages people to use a DST, analyzing how DSTs are used (e.g., what functionalities are leveraged and how), and evaluating the extent to which the DST improves decision-making. In this review, we summarize the state of the literature that evaluates how wildland fire DSTs are used in the field and the extent to which these DSTs help decision-makers improve decision quality. To date, the field of wildland fire DST evaluation has developed somewhat separately from the decision science literature on DST effectiveness and decision quality in natural resource management. Consequently, we begin with an overview of the larger natural resource management and natural hazard literature on DSTs to synthesize criteria for DST success. We then summarize the key findings from the social science of wildland fire DST use, which include common barriers and facilitators to DST adoption and use, as well as examples of use-cases for various DSTs. We conclude with future directions for DST evaluation research, highlighting the need for more consideration on what makes a DST not just a communication, information provision, or decision documentation tool

but a successful *decision support* tool by assessing how DSTs influence decision quality.

Frameworks for evaluating DSTs in natural resource management and natural hazards

There are multiple ways to assess the success of a DST from the larger literature on natural resource management and natural hazards (Stoltz et al. 2023). Ideally, the criteria for success for a DST should be considered and established before the DST is distributed to its intended audience (Moser 2009). At the most basic level, a DST, similar to scientific information more broadly, may be considered a success if it is used by the intended audience or meets the needs of the intended audience and their specific context and values (McNie 2012). Additionally, while user satisfaction or increased confidence in decision-making may be important indicators of DST adoption, self-reported increases in confidence may not be related to improvements in decision quality and should not be used for evaluating DST effectiveness (Wilson and Arvai 2006).

One way to conceptualize what makes something a successful *decision support tool* and not a successful collaborative, information provision, or decision documentation tool is the extent to which it *improves decision quality*. It is widely recognized that in natural resource management, outcomes are categorized by risk and uncertainty. In wildfire, risk and uncertainty pose considerable challenges for selecting strategies and tactics that maximize outcomes (Thompson et al. 2017; Dunn et al. 2017). Further, focusing on immediate or short-term outcomes such as minimizing fires at the smallest possible size can lead to worse overall outcomes in the long run (Calkin et al. 2015), and an emphasis on outcomes may encourage risk-averse decision-making disproportionately weighted toward short-term impacts (Maguire and Albright 2005; Wilson et al. 2011). Consequently, many scholars argue that the quality of a decision ought to be based on the quality of the decision-making *process* rather than the final outcome (Gregory et al. 2012; Thompson et al. 2016; Runge 2020; Árvai and Gregory 2021).

There are several characteristics associated with a high-quality decision-making process and thus decision quality relevant to the evaluation of wildland fire DSTs. One important characteristic of high-quality decisions is *internal consistency*: the decision reflects the preferences decision makers claim to prioritize (Árvai and Gregory 2021). In the context of decision support, preferences are attitudes about the desirability of expected outcomes (Warren et al. 2011). For example, a fuels manager may consider three outcomes when planning a fuel treatment: cost, acres treated, and smoke burden on local communities. The fuels manager may care about those objectives in that order. Preferences are used to identify superior alternatives by informing tradeoffs between objectives. Put another way, to be internally consistent, decision makers need to make decisions in line with their values, beliefs, and contexts (Wong-Parodi et al. 2020).

Under this paradigm, wildland fire DSTs are effective when they help decision makers form, clarify, and articulate preferences, understand how different decisions or courses of action will affect their preferences, and choose courses of action that prioritize those preferences accordingly. Importantly, we do not advocate that decisions are only high-quality and DSTs are only effective when decision-makers can perfectly articulate their preferences and choose the alternative that maximizes stated preferences. Even with structured decision processes intended to guide decision makers through preference articulation through alternative selection, decision makers struggle to maximize expected utility (Bessette et al. 2016; Martin 2021) and express inconsistent preferences (Bessette et al. 2021). Further, when decisions are made collaboratively and decision makers must balance across multiple, often competing attributes, it is unlikely there is only one optimal decision. Thus, a realistic standard for DSTs would not be perfect alignment with stated preferences but instead a *reasonable approximation* of stated preferences or improved alignment with stated preferences compared to a no-tool alternative.

Alternatively, in contexts where it would be unrealistic to evaluate internal consistency, it may be more appropriate to evaluate the extent to which the information a DST provides is relevant and useful for preference-consistent decision-making (Pearman and Cravens 2022). Notably, this is distinct from the criteria for the broader term *usable science,* which should be contextual, credible, trusted, and understood (McNie 2012). Usable science supports a variety of tasks and contexts but is a more general term that acknowledges the critical importance of the context in which and approach with which science is developed as crucial to its utility to decision-makers (McNie 2012). In the same way tools for trust building, collaboration, or decision documentation are not necessarily *decision support* tools, usable science may not be relevant for preference-consistent decision-making. From a cognitive perspective, information is *usable for decision-making* when it helps users understand the decision context well enough to make preference-consistent decisions (Wong-Parodi et al. 2014; Wong-Parodi and Small 2021). Research suggests four criteria of usability for decision-making:

1. Knowledge of decision-relevant facts
2. Ability to integrate facts and values to form consistent preferences

3. Active mastery to make sound inferences with data
4. Ability to understand linkages between systems to anticipate unintended consequences

As a caveat, the assumption that the only thing experts need to make a high-quality decision is the "right" information is a version of the information deficit model of communication (Árvai and Gregory 2021). While information that does not meet the criteria of usability is unlikely to improve the quality of decision-making, the mere provision of even usable information does not prove the tool is facilitating high-quality decision-making in the field. For example, in fire response, additional information does not necessarily improve the accuracy of fire manager decision-making, and too much information can contribute to information overload (McLennan et al. 2006; Drews et al. 2015, Rapp et al. 2021).

Finally, while these criteria evaluate the information provisioned by a DST, some wildland fire DSTs are not just information tools, but *decision structuring tools*. Thus, it is important to understand the extent to which they support or facilitate a high-quality decision process. A high-quality decision process is one where values, consequences, and tradeoffs are made explicit, and the final decision is tractable, i.e., transparent and defensible. DSTs are thus successful to the extent they support and contribute to the characteristics of a high-quality process. For example, Wong-Parodi et al. (2020) argue successful DSTs should have at least one key 'characteristic of success' that contributes to high-quality decision-making.

From Wong-Parodi and colleagues (2020, pg. 55):

> *(1) clearly define goals – describe the desired goals and nature of the decision that needs to be made, (2) identify alternatives – clarify and list possible paths of action, (3) obtain relevant information – collect high-quality decision-relevant evidence, (4) articulate values - voice individual and collective values, views, and preferences in relation to the decision that needs to be made, (5) evaluate alternatives – weigh the alternatives in light of the relevant information and articulated values, and (6) monitor outcomes – review decision, as well as document outcomes.*

Under this paradigm, the goal of DST evaluation is not to assess final decision-making and preference consistency, nor the information provisioned by the tool, though information provision may be an important part of the decision structuring process. Instead, the goal is to assess whether the process and steps the decision support tool walks users through aligns with the processes associated with decision quality.

Methods

Social science of wildland fire decision support tool use

To summarize the nascent field of wildfire DST evaluation and use, we conducted a review of the relevant social science literature. In our review, we sought qualitative social scientific research that evaluates how fire practitioners have used existing DSTs in the field. Only articles that included a qualitative interview, focus group, or open-ended survey response method to evaluate decision support tool use in the field were included. We focused on qualitative studies for their "thick description", that is to say, their ability to explore DST usage in context and as an action in a social world (Kostova 2017). We focus only on existing DSTs, which we consider named DSTs in papers. We do not review studies of just information, e.g., weather information or fire behavior analytics that are not presented as part of a larger existing DST (see Rapp et al. 2021 for an example of an information-only excluded study). We also exclude studies that focus on hypothetical use and intended or desired future use. We focus only on practitioners and managers and exclude studies that focus on members of the public using fire DSTs. Finally, we exclude papers that describe case studies or examples of how a DST was used in the field but do not provide a clear description of their methods for gathering user feedback. We exclude these studies because we cannot evaluate the rigor or appropriateness of their social scientific methods, or clearly delineate what is manager feedback versus author interpretation. We use the social scientific literature on wildfire DST evaluation and use to answer several key questions: What are common barriers, facilitators, and uses of wildfire DSTs identified across social science studies? What are the characteristics of "good" wildfire DSTs, according to these studies? How do existing wildfire DSTs contribute to decision quality?

We collected articles using Scopus and Web of Science search engines. Our search used the following terms (and relevant permutations): decision support (decision analysis, risk analysis, etc.), fire management (hazardous fuels, managed fire, etc.), and qualitative (survey, interview, and social science) in the title, abstract, and keywords. We did not include a lower bound for the date range. We conducted the search in January 2026 and set the upper bound for the range to December 2025, inclusive. The intersection of these search terms yielded 558 unique articles. We reduced this pool to 10 peer-reviewed articles after two phases of trimming, first reading abstracts ($n=22$) and second reading the body text, removing any unrelated literature. For each of these papers, we conducted a cited reference search, going through each paper's works cited and through the GoogleScholar "cited by". This yielded an additional 3 papers, which were also

cited reference searched. Our final pool of peer-reviewed articles ($n=13$) included papers about users in the USA ($n=11$), Canada ($n=1$), and Australia ($n=1$). Consequently, although we did not limit our search terms to these countries, our pool of manuscripts is geographically limited.

Because there are relatively few peer-reviewed articles that met our criteria, we also incorporated grey literature based on qualitatively collected data to bolster our summaries (Benzies et al. 2006). The pace of technological development warrants collecting the most recent information, and such products often have a shorter path to publication than peer-reviewed literature. Given the lack of robust cataloging and identification of grey literature, we limited this search to organizations connected to any of the authors listed on the 8 peer-reviewed articles found by our initial search, using the same search terms. This resulted in the inclusion of 14 additional grey literature papers, all from the USA. We refer to "articles" when discussing only peer-reviewed academic literature, while we use "papers" to refer to the full body of work we analyzed. These 27 papers provide insight into the overall trends in wildfire decision support tool social science (Table 1). Importantly, because these papers are not geographically representative, we have limited ability to say how decision support tool uses, barriers, and facilitators vary across cultures and countries.

The authors used a multi-step coding process to analyze the papers (Creswell and Creswell 2017). We used *Dedoose*, a qualitative data analysis software to code and analyze the papers. First, the authors created parent codes based on the guiding questions to identify barriers, facilitators, and uses of DSTs. Notably, the difference between a barrier and a facilitator is largely just framing;

Table 1 Papers reviewed; paper type; wildfire stage of focus: pre-fire, fire response, or post-fire; and method used. SS interviews mean semi-structured interviews

Papers	Paper Characteristics					
	Method Used	***Peer-Reviewed Article***	***Grey Literature***	***Pre-Fire***	***Fire Response***	***Post-Fire***
Aldworth et al. 2023a	SS Interviews		X		X	
Aldworth et al. 2023b	SS Interviews		X		X	
Aldworth et al. 2024a	SS Interviews, Participant Observation		X		X	
Aldworth et al. 2024b	SS Interviews, Participant Observation		X		X	
Aldworth et al. 2024c	SS Interviews, Participant Observation		X		X	
Aldworth et al 2024d	SS Interviews, Participant Observation		X		X	
Beeton et al. 2022	Survey		X		X	
Beeton et al. 2025	SS Interviews, Survey	X			X	
Buettner et al. 2023	SS Interviews	X		X		
Buettner et al. 2025	SS Interviews, Field Observation	X		X		
Caggiano et al. 2021	SS Interviews		X		X	
Colavito 2021	SS Interviews	X		X		
Dunn and Wolk 2023	SS Interviews		X	X		
Ferguson et al. 2024	SS Interviews	X		X	X	
Fillmore and Paveglio 2023	SS Interviews	X			X	
Greiner et al. 2020	SS Interviews		X	X		
Greiner et al. 2021	SS Interviews	X		X		
Huayhuaca and Caggiano 2021	SS Interviews		X	X		
McFayden et al. 2022	SS Interviews, Survey	X			X	
Neale 2016	SS Interviews, Workshop	X		X		
Noble and Paveglio 2020	SS Interviews	X			X	
Rapp et al. 2020	SS Interviews	X			X	
Schultz et al. 2020	SS Interviews		X		X	
Schultz et al. 2021	SS Interviews	X			X	
Toombs et al. 2018	SS Interviews	X				X
Toombs et al. 2020	SS Interviews		X			X
vonHedemann et al. 2023	SS Interviews		X		X	

in our coding and summary we match the framing used by the studies. Next, the authors developed and applied preliminary child codes designed to summarize key themes (e.g., "Resources and Capacity" and "Cultural" as barriers). Two authors refined and finalized the preliminary child codes through discussion. Each paper was coded by two authors with the finalized coding scheme. Barriers, facilitators, and common uses are categorized by theme (Table 2).

Results

Papers covered a variety of DSTs across all stages of fire management, with most papers covering DSTs intended for pre-fire planning and fire response. Some papers provided an in-depth exploration of one DST: we describe the tools explored in these papers in Table 3.

Barriers to DST adoption and use

The literature describes several barriers that limit DST awareness, adoption, and full engagement. We describe the primary barriers as (1) communication failures, (2) cultural barriers, (3) landscape characteristics, (4) resource and capacity constraints, and (5) user issues.

Communication failures

Communication failures cover barriers related to knowing about a DST or knowing how one can, should, or must engage with it. For example, PODs users mentioned a desire for more clarity from agency leaders about the intended use of PODs, and whether agency leaders were committed to their use (Greiner et al. 2020). Similarly, potential fire response users described that insufficient communication from local managers about how PODs could assist the incident management team hindered use (Caggiano et al. 2021). This highlights a communication breakdown between two types of managers. In comparison, ISAP users mentioned experiencing communication challenges between incident management, agency administrators, and other partners that had a negative impact on the use of ISAP (Aldworth et al. 2024a). For example, participants shared that changes to decisions appeared to occur after ISAP meetings and the justification for those changes was often not well documented or communicated, frustrating those users who were excluded from the decision-making process and eroding trust (Aldworth et al. 2024a). Additionally, while some respondents hoped ISAP would improve how on-the-ground firefighters understand their tactics to contribute to overall strategy, it was unclear if ISAP was successful in that regard (Buettner et al. 2025). Overall, communication failures and a lack of clarity created barriers for these tool users to fully engage.

Cultural barriers

Cultural barriers were common across DSTs. These include the social beliefs and practices that create barriers to engaging with DSTs. For example, for multiple tools, agency staff expressed reluctance to embrace new approaches or expressed a general culture of reluctance and suspicion that the DST would not "stick" (Greiner et al. 2020, 2021). Potential users could distrust models for a variety of reasons (Ferguson et al. 2024). They described that models were inaccurate and did not reflect on-the-ground conditions (Schultz et al. 2021; Aldworth et al. 2023b), they could be biased to individual perceptions or were overly subjective (Aldworth et al. 2024b), and they were not transparent in how they generated results (Aldworth et al. 2024a, 2024b).

The history of fire suppression in the US and the culture of firefighting within the agencies to put fires out as quickly as possible have influenced the use of several of the DSTs, including PODs, RMA, and WFDSS in multiple ways. First, for fire response DSTs, fire managers describe feeling pressure to use suppression-only or aggressive tactics. Fire managers may be hesitant or feel unsupported to pursue indirect strategies. When there is a cultural expectation or social pressure to aggressively suppress fires, there is little discretion or decision space to authentically engage with DSTs (Schultz et al. 2020, 2021; Greiner et al. 2021; Buettner et al. 2023). Second, cultural beliefs about what makes a "good" fire manager could limit DST adoption. Some potential users of RMA, WFDSS, and ISAP expressed they were unnecessary because of personal expertise or cultural beliefs that a "good" fire manager does not need the information they provide (Rapp et al. 2020; Schultz et al. 2020; vonHedemann et al. 2023; Buettner et al. 2025).

Landscape characteristics

Landscape characteristics can act as barriers that limit users' decision space and ability to authentically engage with DSTs. Local ecological conditions influence the ability of managers to capitalize on the full potential of PODs, including fuels, weather, proximity to values at risk, volume of roads, vegetation type, slope, and place of the ignition (Greiner et al. 2020). Additionally, conditions vary year to year, meaning that PODs need to be maintained for accuracy as conditions change to make them relevant to the decision context (Greiner et al. 2021). Similarly, with RMA, local biophysical conditions and fire history impact the decision space for managers. In areas where on-the-ground conditions are likely to lead to long-duration and hazardous fires, line officers have expressed that they will likely suppress fires at the smallest possible size (Schultz et al. 2020, 2021).

Table 2 Common barriers, facilitators, and uses described in the DST social science literature

Parent Code	Child Code	Description	Example
Barriers	**Communication failure**	Failure to communicate how a DST can, should, or must be engaged with.	"However, POD data was not consistently transferred to incoming teams, nor was it consistently made available to incident management team operations and planning sections, nor to boots-on-the-ground fire resources. Local managers may not have effectively communicated how PODs could help the incident management team save time by more efficiently identifying potential control lines to scout, improve, or use during the fire." - Caggiano et al. 2021
	Cultural barriers	Social beliefs and practices that limit users' ability to engage with or use the information in DSTs, such as social pressure to pursue a particular strategy, general reluctance to adopt new tools, beliefs about what makes a "good" fire manager, etc.	"People said some USFS staff members can be reluctant to embrace new approaches, which they anticipated could be a factor affecting the use of PODs. Many interviewees were unsure if PODs would be collectively embraced and carried forward within the agency. Interviewees also explained there is often hesitancy to accept new approaches because the Forest Service is 'constantly being sold on some new framework or technology, and they're just hesitant to adopt it first because this will be put on the shelf. It will be something to do next year.'" -Greiner et al. 2020
	Landscape characteristics	Physical or ecological such as fire risk or vegetation, associated with lack of DST use or adoption	"Interviewees noted that local biophysical conditions and fire history affect line officers' decision space. These factors can limit the ability to fully embrace some of the dialogue and tools that RMA offers for considering tradeoffs and response options." - Schultz et al. 2020
	Resources and capacity	Social, financial, technical, etc. Resources that create barriers to adoption, engagement, and maintenance of DSTs	"We also found that only a small number of users actually possess the skill to operate the WFDSS program, and that these users help to incorporate other users' contributions made possible by the program. Moreover, the concentration of skilled WFDSS 'drivers' appears to be consolidating into a small subset of users capable of running the program and who bear most of the responsibility for running the program." - Fillmore and Paveglio 2023
	User issues	User-interface features or missing functionality that make DSTs difficult or less effective to use and discourage adoption and engagement	"A substantial amount of time was spent getting all participants on the same page, so starting the process with an example of how RADS has worked in other areas would be helpful. One identified challenge was that each agency has different data tracking mechanisms, so trying to pull data together across the landscape was difficult. Participants also mentioned that it would be valuable to understand how RADS results fit in with a variety of other newer prioritization and risk assessment frameworks, such as the Colorado State Forest Service Forest Action Plan and US Forest Service scenario investment planning. There was also confusion about how Potential Operational Delineations (PODs) as a management tool compares/relates to RADS" - Dunn and Wolk 2023

Table 2 (continued)

Parent Code	Child Code	Description	Example
Facilitators	**Awareness of DST before use**	Awareness and familiarity with a DST, even without formal training, before needing to apply the tool in the field	"Knowledge of RMA tools is growing but remains limited: Regional- and Forest-level personnel and Type 1/Type 2 IMT members we interviewed were familiar with RMA. However, multiple interviewees cautioned that there is still variability in familiarity among potential users, particularly AAs and Type 3 organizations." - Aldworth et al. 2023b
	Cultural facilitators	Social beliefs and practices that facilitate DST use, such as support from leadership, agency buy-in to use a tool, receptiveness to novel tools, etc. This is distinct from individual, one-on-one relationships with people.	"Interviewees said there is a need for stronger agency-wide commitment and leadership around risk-informed decision making. RMA deliverers in particular felt that the approach was unlikely to be successful without communication and commitment from agency leadership about the importance of using im-proved analytics for decision making. For instance, one person explained, 'Our culture is a significant hindrance to the acceptance of this type of activity just because it's simply different…. A lack of general leadership strength really inhibits something like this being successful…. We have to be able to actually implement these ideas consistently and methodically across the entire agency'" - Schultz et al. 2020
	Formal training	Planned or structured opportunities to become more proficient with a DST, such as curriculum, help resources, shadowing, etc.	"Rather than discard this pillar, many said additional training may be warranted to effectively implement the probability of success portion of the ISAP and minimize subjectivity." - Aldworth et al. 2024b
	Interpersonal relationships and trust	Relationships between individuals (e.g., potential user and researcher, or fire manager and technical analyst) that support DST use	"During the interviews [discussing CFFDRS], the importance of regular informal communication was a recurring theme, with participants saying that they benefitted from building 'close working relation-ships' and being able to call [colleagues] up by telephone or say, 'I'm coming up… can I pop in and talk with you?'" -McFayden et al. 2022
	Resources and capacity	Social, financial, technical, etc. Resources that facilitate adoption, engagement, and maintenance of DSTs	"Analytical capacity: Additional investments in analytical capacity to develop and use risk-informed spatial analytics are needed. Funding for analysts and support staff could help develop and interpret RMA analytics and provide additional services under the RMA program of work." - Beeton et al. 2022
	User-friendliness	User-interface features or desired features that make DSTs easy to use and encourage adoption and engagement	"The RMA dashboard and tools were reportedly easy to use and interpret and accurately reflected conditions on the ground, insofar as users understood the underlying assumptions. Interviewees reported that because these tools were so easy to use, they helped to facilitate strategic dialogues among a diverse cadre of participants who might not otherwise be able to fully engage" - Aldworth et al. 2023b

Table 2 (continued)

Parent Code	Child Code	Description	Example
Common uses	**Information seeking and informing decisions**	Information provision, often stated through phrases like "getting a sense", "just to see" getting information, "getting up to speed", any generic "to get information"	"All 19 respondents, regardless of actual level of use initially sought to employ RECOVER for a variety of duties and objectives. For instance, obtaining data and information on burn severity, debris flow probability and pre-fire vegetative cover were the most common responses..." - Toombs et al. 2018
	Group communication	Communication in a group to build a shared understanding, maintain a shared picture, to bring people together and have collaborative discussions	"RMA facilitated dialogue between local units, agency administrators, IMTs, and cooperators." - Beeton et al. 2022
	Crafting messages for one-way communication	Communication that is intended to craft a message for someone to passively receive, rather than to facilitate or hold dialogue	"The use of advanced fire behavior models, weather forecasts, historical data, and RMA analytics allowed the IMT to frame potential strategic actions in relation to their probability of success and develop a cohesive rationale to share with boots-on-the-ground firefighters about why putting fire back on the landscape was a risk-informed approach." - Aldworth et al. 2024a
	Confirming knowledge and increasing confidence	Gut-checking, double checking, confirming intuition or knowledge, seeking confirmation	"Although managers reported RMA tools did not lead to changed actions, the tools helped confirm courses of action or helped determine if additional ground-truthing was needed." - vonHedemann et al. 2023
	Decision documentation	Documenting decisions to have more tractability and transparency, to explain rationale, any form of using a tool to write down what was done or to create a record of decision making	"Our findings indicate that fire managers did not always feel that WFDSS outputs changed the course of fire management decisions because the lack of timely WFDSS decisions reinforced their reliance on experience and intuition. As a result, managers used WFDSS most often to justify and document decisions after the fact." - Noble and Paveglio 2020

Table 2 (continued)

Parent Code	Child Code	Description	Example
Decision effectiveness uses	**Identifying and articulating objectives**	Using a DST to list or determine values, objectives, preferences, etc.	"Line of officers especially valued the products that allowed them to consider a variety of values at risk and tradeoffs among different strategies in a structured, communicable format. As one line officer explained, 'Those deliberate conversations about what truly are the values at risk—that is what I took away from RMAT.'"-Schultz et al. 2021
	Constructing alternatives	Using a DST to come up with possible courses of action, things to do, or alternatives	"PODs were used to help identify contingency containment lines in case the fire breached primary lines. These POD boundaries and potential control lines were identified, scouted, and in many cases improved through mechanical thinning and burn out operations. A portion of these lines were engaged and held fire." - Caggiano et al. 2021
	Evaluating consequences and making tradeoffs through consistent approaches	Evaluating outcomes and choosing an alternative. Using a tool to consider or be aware of tradeoffs, to weigh consequences of different actions, or assess feasibility	"Participants indicated RMA tools were used by firefighters, agency staff, and others to quickly identify locations for containment lines, evaluate fire responder risks (e.g., snags and evacuation times), estimate the probability of containment success, and determine opportunities and challenges of alternative strategic action" – Beeton et al. 2025

Table 3 Description of decision support tools assessed through in-depth studies of one DST

Decision Support Tool	Description of DST	Citation(s)
Canadian Forest Fire Danger Rating System (CFFDRS)	The CFFDRS is the fire danger and behavior system used in Canadian fire management practices. This tool has four modules that include the Fire Weather Index, the Fire Behavior Prediction System, the Fire Occurrence Prediction, and Accessory Fuel Moisture System.	McFayden et al. 2022
The Incident Strategic Alignment Process (ISAP)	The ISAP is a management framework for considering risk and developing strategy for wildfire management. It is informed by spatial and fire behavior analytics and is a collaborative and iterative conversation among incident management teams, agency administrators, and external partners.	Aldworth et al. 2024a, b, c, and d; Buettner et al. 2025
PHOENIX RapidFire	PHOENIX is a two-dimensional fire behavior simulator that predicts for fire behaviors while also including atmospheric aspects such as ember transport and plume development	Neale 2016
Potential Operational Delineations (PODs)	PODs are a strategic planning tool used to inform fire response decisions. PODs help fire managers identify the most suitable and effective control lines (e.g. roads, rivers, ridges, streams) on the landscape that could be used to contain a wildfire (Buettner et al. 2023). PODs use some of the same analytical tools as RMA, and PODs are also included on the RMA Dashboard.	Buettner et al. 2023; Caggiano et al. 2021; Greiner et al. 2020 and 2021
Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER)	RECOVER is the result of a collaboration between NASA's Applied Sciences Program, NASA Godard Space Flight Center, and the Idaho State University GIS Training and Research Center. RECOVER uses earth observation imagery and GIS technology to give wildfire managers rapid access to relevant information for post-fire recovery.	Toombs et al. 2018; Toombs et al. 2020
Risk Assessment Decision Support (RADS)	RADS is an outcome-based planning framework that uses geospatial modeling within a collaborative process and includes geospatial vegetation and land use data, wildfire probability and behavior calculations, and locally relevant information and values to determine where risk reduction per dollar spent is greatest.	Dunn and Wolk 2023
Risk Management Assistance (RMA)	RMA is a system designed to provide on-the-ground support and virtual assistance on wildfires. This support can be in the form of incident timelines, hazard maps, suppression difficulty index assessments, identification of potential control locations, and risk trade-off analyses.	Aldworth et al. 2023a and b; Beeton et al. 2022; Beeton et al. 2025; Caggiano et al. 2021; Schultz et al. 2020 and 2021; vonHedemann et al. 2023
Wildland Fire Decision Support System (WFDSS)	WFDSS is a web-based platform that helps federal fire managers and agency administrators to improve decision-making during wildfire incidents. A WFDSS decision document typically includes maps, figures, tables and text that assess values at risk, recommend fire response, provide management objectives, outline a course of action with rationale, provide estimated cost of management, and other relevant information.	Fillmore and Paveglio 2023; Noble and Paveglio 2020; Rapp et al. 2020
Wildfire Risk to Communities (WRC)	WRC is a free web-based USDA Forest Service tool to better understand risk across the United States with datasets for risk to homes, burn probability, community wildfire risk reduction zones, exposure type, flame length, wildfire hazard potential, and wildfire consequence.	Huayhuaca and Caggiano 2021

Further, managers have had experiences where evacuation data presented by the RMA team did not account for conditions that limited access to certain roads and the inaccuracy and lack of knowledge of the landscape characteristics limited the tool's utility (Schultz et al. 2020).

Resources and capacity

Logistic barriers related to limited resources and capacity are very common across DSTs. Resource constraints limited local and organizational capacity to devote to training and education, applying DSTs in the field, and keeping DSTs up to date. These constraints can interact with each other. For example, users described limited opportunities to become proficient in WFDSS, and as a result there is a shrinking pool of "drivers" who enter in the data and interact with the program (Fillmore and Paveglio 2023). Simultaneously, lack of capacity during fire response strains the ability for WFDSS users to update information as a fire unfolds on the landscape (Rapp et al. 2020). Similarly, resource constraints and limited staff capacity create challenges for keeping PODs up-to-date and accurate year-to-year (Greiner et al. 2020). Consequently, resource and capacity barriers can undermine the timeliness and perceived accuracy of tools, exacerbating cultural barriers and user issues. The sheer number of tools can also prove a challenge for managers (Colavito 2021), as one manager described the landscape of weather tools: "There's just so much information... it's nearly impossible for one person to be familiar with everything, and identify what's best, or what suits their need or purpose at the time" (Ferguson et al. 2024, pg. 798).

User issues

User issues as barriers to tool use ranged from general usability (e.g., being too complicated) to lacking specific important data layers and distrusting the accuracy or output of the models. For data outputs that the public might use, (i.e., RMA and RADS), users expressed that language barriers for non-English speakers could limit the use of the tool as well as the input that those populations could give (Huayhuaca and Caggiano 2021; Dunn and Wolk 2023). Many DSTs are perceived as complex and challenging to use (Noble and Paveglio 2020), and the information they provide can be difficult to interpret (Colavito 2021). Users may also have critiques that tools need key functionality to be useful. For example, RMA users shared a desire for more accurate data layers to improve outputs (Schultz et al. 2020, 2021; Aldworth et al. 2023b; vonHedemann et al. 2023), and for better usability with slower internet connection speeds (Aldworth et al. 2023b).

Facilitators to DST adoption and use

Similarly, there are a variety of facilitators for tool adoption and use described by researchers, many of which are conceptually similar to barriers. The main types of facilitators we identified included (1) awareness of DST before use, (2) cultural facilitators, (3) formal training, (4) interpersonal relationships and trust, (5) resources and capacity, and (6) user-friendliness.

Awareness of DST before use

Because there are numerous DSTs for managers to evaluate for use, boundary-spanners can play an important role in increasing awareness and communicating the functionality, purpose, or utility of a DST (Colavito 2021). Awareness of and familiarity with DSTs prime potential users to be more comfortable interacting with them and are necessary precursors for DSTs that are not mandatory. For example, for RMA, multiple papers described the importance of being aware of and familiar with the tool before a fire was on the landscape. Users described that exposure to and familiarity with RMA (distinct from formal training) in a pre-fire setting made people more comfortable using it during fires (Schultz et al. 2020, 2021). Users described that awareness of RMA was inconsistent (Aldworth et al. 2023b), but they expected increased adoption and comfort with RMA as awareness of the tool organically grew (Beeton et al. 2025).

Cultural facilitators

Like cultural barriers, cultural facilitators are the social beliefs and practices that facilitate adoption and use of DSTs. For example, whereas public pressure to manage fires as full suppression may limit engagement with DSTs, public support for other-than-suppression strategies, or lack of public pressure to aggressively suppress, creates a larger decision space for fire managers to engage with and consider different actions based on DST output and information (Greiner et al. 2020, 2021; Buettner et al. 2025). Users mentioned that receptivity to, and support and clear intent, for DSTs from leadership were critical for adoption. Leaders could include local champions from collaboratives, NGOs, or agencies (Greiner et al. 2021). Users described having a line officer, incident commander, or other leader who was receptive to new tools facilitating RMA and ISAP adoption for fire response (Schultz et al. 2020; Beeton et al. 2022, 2025). Simultaneously, clear direction and intent from higher agency levels played a critical role. Users and potential users described wanting a clear leadership vision from the forest and regional levels for how individual tools such as RMA should be incorporated into fire management (Greiner et al. 2020) and how much fire managers should engage

with or prioritize paradigms like risk-informed decision-making (Schultz et al. 2020). Users highlighted that clear support and intent from leadership could help fire managers feel empowered or supported to use DSTs in the absence of clear public support (Schultz et al. 2020).

Formal training

Formal training is an important facilitator for sustained use and engagement with DSTs. Users and potential users described a wide variety of training opportunities they believed would be helpful, including help menus on websites, online webinars and trainings, brief refresher courses, formal curriculum, shadowing opportunities, and access to coaches and support staff during incidents. Users advocated for training in how to use tools but also training in underlying concepts such as risk management (Schultz et al. 2020, 2021; Colavito 2021). The myriad modes of training people described, ranging from brief reminders and prompts to involved, in-person mentorship, reflect the diversity of users for DSTs (e.g., highly skilled "drivers" to casual users, see Fillmore & Paveglio, 2023) the variations in time and capacity to dedicate to training, and the range in learning styles that most benefit individuals.

Interpersonal relationships and trust

A recurring finding across studies is that interpersonal relationships are important for creating trust in tools and the outputs they generate and for socializing tools (McFayden et al. 2022; Ferguson et al. 2024). For example, line officers and IMT members value and trust fire behavior models in WFDSS more when they trust or have a personal relationship with the technical specialist generating the output (Rapp et al. 2020). Potential users reported greater comfort with RMA when they knew someone on the RMA team and more skepticism when RMA team members were perceived as "outsiders" (Schultz et al. 2020, 2021). Existing relationships and connections to meteorologists and local National Weather Service staff facilitate clear and effective weather information sharing (Ferguson et al. 2024). Relatedly, existing strong interpersonal relationships help users navigate through DSTs and more deeply engage with structured processes (Greiner et al. 2021; Aldworth et al. 2024a). Because interpersonal relationships influence tool adoption and engagement, communication and interpersonal skills are important for increasing buy-in and willingness to engage with DST output (Rapp et al. 2020; Buettner et al. 2023). Further, co-production of the DSTs or the outputs associated with them increases trust and buy-in for outputs and products (Rapp et al. 2020; Colavito 2021; McFayden et al. 2022; Aldworth et al. 2024a).

Resources and capacity

Resources and capacity as barriers versus facilitators are primarily a matter of framing. When framed as facilitators, capacity and resources varied from general observations that more capacity, or investments in capacity would be necessary for DST success, to specific examples of what would be useful. For example, users highlighted dedicating local-level staff capacity to maintaining and improving PODs would be preferable to increasing the capacity of PODs developers or research institutions (Greiner et al. 2021; Buettner et al. 2023). ISAP users valued having a dedicated facilitator to guide them through the process, though there were a variety of opinions on who the facilitator should be or what makes an effective facilitator (Buettner et al. 2025). Further, while some respondents want additional capacity to have technical analysts on site for fires rather than working remotely (Rapp et al. 2020), others highlighted that having remote teams of technical analysts would add flexibility (Schultz et al. 2020).

User friendliness

User friendliness is the positive framing of user issues. Users described improvements that had been made to existing tools to streamline and improve them (Schultz et al. 2020). Users observed aspects of tools they enjoyed, such as intuitive navigation, easy-to-use workflow, clear structure, and visually appealing outputs (Huayhuaca and Caggiano 2021; vonHedemann et al. 2023; Aldworth et al. 2024c, 2024b). They also recommended specific features or desired capabilities for existing tools, which ranged from changes to user interface (e.g., what colors maps are printed in) to improved analytical capacity. Users emphasized that keeping tools like RMA updated and underlying models accurate is important for maintaining easy use with limited lift (Beeton et al. 2022).

Common ways DSTs are used in the field

We synthesize the variety of uses described for DSTs. These uses are intended to provide a summary of the different ways users and researchers have conceptualized the utility of DSTs.

Information seeking and informing decisions

At their most basic, DSTs provide information and inform decisions. As a respondent described in an article by Ferguson et al (2024, pg. 798): "you're always looking, hunting, checking, seeing if what you're seeing, what you're observing, what others are giving you makes sense." Without further detail, it is difficult to assess what information people look for, how they apply it to the decision-making process, or what the outcome

of using that information is. Using DSTs as information provision tools may be important for efficiently and accurately gathering background information on a topic. For example, transitioning IMTs may use RMA to orient to a new landscape and "get up to speed" (Aldworth et al., 2023b, 2023a) WFDSS contains information on fuels and fire behavior (Fillmore and Paveglio 2023); and WRC provides background information for people just entering the wildfire risk mitigation space (Huayhuaca and Caggiano 2021). Overwhelmingly, RECOVER users reported the information it provided helped them make better-informed decisions (Toombs et al. 2018). DSTs can also be the mechanism by which information is gathered, such as PODs being used to capture and formalize expert knowledge (Greiner et al. 2021). Users may also gather information from specific DSTs because of grant or policy requirements (Huayhuaca and Caggiano 2021; Dunn and Wolk 2023; Buettner et al. 2023), but without further context it is difficult to know the unique effect of using DSTs to get this information.

Group communication

Authors reported an important function of several DSTs was the way they were used to support collaborative or team discussions and decision-making. This could occur through several mechanisms. The process of using a DST could require the input of multiple people, increasing the diversity of viewpoints contributing to the decision process (Buettner et al. 2025). The DST could provide a skeleton or structure for how to conduct conversations in a group (Buettner et al. 2025). The information provided by the DST could support a shared understanding or common operating picture between group members, across agencies, and across disciplines (Colavito 2021). Finally, the information provided by the DST could spur collaborative discussions. In pre-fire planning, going through a RADS process helped participants feel heard and ultimately resolve conflicts and reach consensus (Dunn and Wolk 2023) and PODs facilitated bringing diverse voices to the table and breaking down agency silos, and in doing so building consensus (Greiner et al. 2020, 2021). In fire response, several DSTs help teams and agency personnel develop and maintain a common operating picture through the information they provide, including ISAP, RMA, and PODs. Users highlighted that WFDSS provides a consistent framework for a process of collaborative reasoning and decision-making (Noble and Paveglio 2020; Fillmore and Paveglio 2023).

Crafting messages for one-way communication

DSTs were also important for crafting messages and supporting communication from managers to broader audiences. In this case, respondents did not describe DSTs as structuring the process of creating messages or communicating; rather, the information provided by DSTs was useful for message framing and crafting. Common audiences for these messages were the public, politicians, collaborative partners, and non-fire agency personnel. For example, users described that PODs and RADS helped visualize areas of high risk to increase public understanding of and support for managers' prioritization decisions (Dunn and Wolk 2023; Buettner et al. 2023). Graphs and handouts from WRC mapping outputs were useful resources for public engagement (Huayhuaca and Caggiano 2021). In fire response contexts, DSTs are used to justify or explain strategies, tactics, and potential management actions to line officers and interested and affected entities perceived to have less experience in fire management (Schultz et al. 2021), and using a DST can improve perceived credibility of treatment decisions (Colavito 2021).

Confirming knowledge and increasing confidence

DSTs were often used to confirm existing knowledge, validate decisions, and increase confidence in decisions. Confirming knowledge, "gut-checking" intuition, and validating existing knowledge can be important for augmenting existing expertise. For example, users described PODs as an intuitive way to validate treatment locations (Buettner et al. 2023). WFDSS is perceived as corroborating expertise (Fillmore and Paveglio 2023); respondents described using it to better understand and tweak their intended strategy through storytelling and "what-if" scenarios (Rapp et al. 2020). However, confirming expertise may also be an exercise in confirmation bias and justifying decisions that have already been made, rather than supporting defensible decision-making. For example, users described RADS as highlighting areas for treatment they already thought were important; RADS provided a framework to justify where they wanted to treat (Dunn and Wolk 2023). Because of time constraints described previously, WFDSS may "follow the decision" (Rapp et al. 2020), and RMA can provide evidence to support line officer decision-making after-the-fact (Schultz et al. 2020, 2021; vonHedemann et al. 2023).

Decision documentation

Related to knowledge confirmation and decision justification is decision documentation. Some DSTs, such as WFDSS and ISAP, are built to be a decision support and decision documentation process; one of the key outputs is a documented (and, in theory, improved) decision on fire response strategy. Finalized POD lines represent the culmination of the PODs' decision-making process. The nested and overlapping nature of DSTs also means tools can contribute to decision documentation processes.

For example, RMA analytics can be used to build justifications for decisions in WFDSS (vonHedemann et al. 2023). Users highlighted decision documentation is important when decisions can be scrutinized after the fact (Noble and Paveglio 2020; Fillmore and Paveglio 2023). In multiple studies, users emphasized that DSTs may help document decisions, but they do not make decisions; behavioral discretion ultimately belonged to users (Neale 2016; Rapp et al. 2020; Noble and Paveglio 2020; Schultz et al. 2021; Colavito 2021). Similar to the ways DSTs confirm knowledge and increase confidence, decision documentation is likely useful when it helps augment expertise and provides a systematic way to create records for decision rationales. However, decisions documented after the fact or as a box-checking activity may not be meaningfully supported by DSTs.

Decision support tool effectiveness frameworks in the wildfire literature

We assessed whether papers had a guiding theory or framework for what constitutes a good, successful, or high-quality DST. Overall, most of the academic papers and all of the grey literature did not include the use of an identifiable DST evaluation framework. Five papers included a framework or guiding theory for their study, but that framework is not about DST success. Buettner et al (2023) and Beeton et al. (2025) explore DST adoption using Diffusion of Innovations, a framework from communications that focuses on how ideas, information, and practices spread from progenitors to adopters (Lemos 2008). Neale (2016) leverages the literature on anticipatory regimes, which is interested in how regimes anticipate and act on perceived future threats (Adams et al. 2009; Anderson 2010) to analyze how PHOENIX serves to make risk "a discrete object of knowledge" (Neale 2016, pg. 2028) that can be projected into a contingent future. Rapp et al (2020) explore the mechanisms by which information influences strategy selection using Recognition-Primed Decision Making, a framework from psychology that focuses on how people, especially experts, make decisions in the field by processing information cues and matching them to previous experience (Klein 2008). Noble and Paveglio (2020) argue that evaluating the success of DST adoption (DSSs in their paper) based on the final decision or outcomes does not provide a clear metric of success. Instead, they argue the success of DST adoption can be assessed through system usage, user satisfaction, and perceived benefits such as perceived increase in decision quality. Notably, they focus on evaluating the process of adopting WFDSS, which is distinct from evaluating WFDSS itself as a DST. In comparison, Fillmore and Paveglio (2023) provide commentary on the usability and usefulness of DSTs from foundational literature on Decision Support Systems, Electronic Data Processing, and Management Information Systems. From this literature, they synthesize key characteristics that DSTs should have related to the usability of information, ease of use and customizability of the tool, and comprehensiveness of decision factors. They synthesize that DSTs (DSSs in their paper) are most useful when they "help guide the aggregation of disparate expert judgments or information, reduce uncertainty of decision inputs and help confirm professional experience or intuition" (Fillmore and Paveglio 2023, pg. 623, citing Sprague 1980, Power 2007). While they find respondents using WFDSS in ways that match these criteria (e.g., integrating perspectives from incident management teams, agency administrators, and resource specialists into a consensus about how to manage a fire), they do not offer a synthesis or commentary on the extent to which WFDSS is a successful or effective DST.

While none of the papers directly focused on the extent to which DSTs improved decision quality, i.e., the extent to which decision makers select a course of action consistent with their stated preferences, it is important to highlight overlaps in these papers with concepts from the broader DST evaluation literature, including where and how DSTs may be helping decision makers (1) identify and articulate objectives, (2) construct alternatives, and (3) evaluate consequences of alternatives and make tradeoffs, through structured or consistent approaches. For example, users highlight that the pre-fire season PODs process can contribute to the consideration of a wider range of objectives during fire response (Greiner et al. 2021), and during fire response can be used to assess potential control lines, which could help fire managers make tradeoffs and evaluate consequences of different actions (Caggiano et al. 2021). Similarly, users describe that RMA can help teams identify values at risk (objectives) and develop strategies (alternatives) based on feasibility and expected consequences (Beeton et al. 2022; Aldworth et al. 2023b, 2023a). PHOENIX allows users to estimate consequences of possible actions and thus may help users construct possible burn plans (alternatives) and assess potential consequences (Neale 2016). Because of known issues with self-reports of improved decision-making quality and confidence (Wilson and Arvai 2006), and the reported tendency to use wildfire DSTs to justify already-decided actions (see Sect. 3.3.4, "Confirming knowledge and increasing confidence"), moving beyond self-reports into more direct assessments is a critical next step for DST evaluation.

Discussion and future directions

As described previously, the existing social science work evaluating wildfire DST use in the field has largely lacked theories or frameworks on decision quality and DSTs. This is not to diminish or criticize these studies, which often have different stated goals such as describing barriers and facilitators to tool adoption, or demonstrating example use cases for potential users. While these studies have not directly evaluated the extent to which wildfire DSTs improve consistency with stated preferences, their results point to some of the ways DSTs may be providing decision-relevant information and decision structuring. For example, a common use and strength of DSTs are the ways they facilitate conversation and shared understanding (e.g., Noble and Paveglio 2020; Beeton et al. 2022; Dunn and Wolk 2023). As communication tools, wildfire DSTs may play an important role in helping decision makers articulate their preferences, reveal tradeoffs across different values, and obtain relevant information from their fellow decision maker or DST user. However, to better understand how wildfire DSTs are influencing decision quality, more work is needed with an explicit focus on decision quality and DST effectiveness. To that end, we recommend several strategies and provide examples of how they could be used with various wildfire DSTs.

It is important to establish the goals of the tool and what effectiveness and success mean according to the tool designers and users (Stoltz et al. 2023). We recommend tool designers use other metrics beyond (or in addition to) adoption rates and frequency of use to measure success and effectiveness of decision support tools. While adoption is certainly a necessary step, it is important to consider the intended purpose. Tool purpose is important for determining the most reasonable criteria for effectiveness. For example, if a tool is intended for information provision, the most appropriate way to assess a tool may be to evaluate the extent to which the information it provides is relevant to preference-consistent decision-making (Wong-Parodi and Small 2021), and users demonstrate they are able to find and apply that information. Alternatively, if the tool is intended to guide decision makers through a structured process, it may be more important to assess if the tool helps decision makers in a particular decision task, such as helping decision makers recognize more tradeoffs (Daw et al. 2015; Hamilton et al. 2019) or create more complete and/or parsimonious lists of objectives (Marttunen et al. 2019).

Evaluation of DST effectiveness and decision quality can occur in the lab and the field. The studies reviewed in this paper focus on use in the field, but simulations have long been an important tool for improving team performance and information provision in wildfire (e.g., McLennan et al. 2006; Wells et al. 2025). In fact, simulations are an important part of tool socialization and training and provide an under-leveraged opportunity for evaluating DST effectiveness. We consider two DSTs presented in this review, RMA and ISAP, and provide potential methods for evaluating their efficacy and impact on decision quality for demonstration. While interrelated (RMA is often used within the operationalization of ISAP), their distinct characteristics—RMA as a source of information to assess a situation vs. ISAP's focus on collaborative decision-making—invite separate approaches for investigation.

As described in the literature, for end users, the perceived intent of RMA is to assist in developing a common understanding of a fire management situation, including risks and hazards, by serving as an expansive, holistic source of information for IMTs and agency administrators or land management unit decision-makers (Beeton et al. 2022). This generally aligns with RMA developer and leadership perceptions. This reputation as a source of diverse and complex information suggests it could be evaluated for how decision-relevant the information it provides is (Wong-Parodi and Small 2021). Thus, a possible measure of DST effectiveness is end-users' ability to find and apply relevant information in RMA about situational factors, risks, and hazards associated with a given scenario. Using the criteria from Wong-Parodi and Small (2021), this could include measuring and assessing, for example, (1) users' incident-specific knowledge of decision-relevant facts, such as potential containment features or likely evacuation times, before and after interacting with RMA; (2) users' ability to integrate facts and values to form consistent preferences by correlating how RMA tools and analytics are used in mock WFDSS decisions and how that relates to clearly articulated preferences and transparent decision-making; (3) users' ability to make sound inferences from the data available; and (4) users' understanding of system linkages to anticipate unintended outcomes by evaluating how managers use national, regional, and local risk assessments available on the RMA dashboard to gauge how long-term risk fluctuates based on fire response management choices in a given situation. Such tests are conducive to a lab or simulation setting where common variables in fire management decision-making, such as fire weather, landscape characteristics, and resource availability can be controlled.

While RMA is an important information provision tool, ISAP is more aligned with a structured decision process tool. One of the primary intents of ISAP is to collaboratively build a shared understanding of four "pillars"—critical values at risk, strategic actions, risks to responders, and overall probability of success for

a given wildland fire incident (Buettner et al. 2025). Evaluating the total impact of the ISAP using a single metric is particularly challenging because of the numerous outcomes the ISAP seeks to improve, including a shared understanding and prioritization of threatened values, improved quality of a risk-informed, durable strategy, elevated comprehension of relevant risks across a landscape, and effective evaluation of the likelihood of a chosen strategy's success in a milieu of complex variables. However, each of the four pillars can function as a separate process researchers can evaluate in a controlled field setting. For example, consider the first pillar, where ISAP users develop a common understanding and prioritization of threatened values. The ISAP is not yet universally adopted among all levels of incident response. This provides an opportunity for natural experiments: do individuals on teams using the ISAP demonstrate more similar mental models of the threatened values than individuals on teams that do not use the ISAP? Do they demonstrate fewer breakdowns in coordinated decision-making (Bearman et al. 2015)?

Future research might evaluate how the ISAP supports the "characteristics of success" described by Wong-Parodi et al. (2020), that is to say, the extent to which the ISAP helps users clearly define goals, identify alternatives, obtain relevant information, articulate values, evaluate alternatives, and/or monitor outcomes. The ability to obtain relevant information can be assessed through the process for measuring the quality of decision-relevant information we described for RMA. We focus on the ways the ISAP may help users articulate values and monitor outcomes. While there are efforts to formally standardize the ISAP, the process has yet to be fully institutionalized. This provides the opportunity to test teams and groups who use the process against those who use other systems. For example, using existing documentation systems, such as WFDSS, researchers could evaluate frequency and type of alternatives identified, and whether or not the users who use the ISAP identify, generate, or select meaningfully different alternatives. For example, are ISAP users more or less likely than non-ISAP users to generate or select strategies that include an indirect attack component? Alternatively, future studies could assess how ISAP shapes the values generated, and discussion around how vulnerable and important those values are. Important attributes to assess may include who the core decision-making team consulted versus who it included in decision-making, how well team members are able to describe the priorities different values represent or how well team members are able to take the perspective of other groups and interests (e.g., how well is the incident commander able to describe the perspective of the line officer and vice versa).

Additionally, it is fortunate that forums already exist that could be leveraged to test the effectiveness of existing DSTs such as the ISAP outside of real-time incident response. Currently, mid-career individuals seeking to obtain a Complex Incident Management Team qualification (the highest type of qualification available in the wildland fire management space in the USA), such as Complex Incident Commander, Complex Operations Section Chief, or Complex Public Information Officer must complete the National Wildfire Coordination Group class "S-520, Advanced Incident Management" where the ISAP and associated incident management concepts are introduced in a classroom setting, and then practiced and tested using multiple incident simulations. In this, students are evaluated by a "coach" who works with them throughout the duration of the class to improve their understanding and execution of incident management tasks, with particular emphasis on how students evaluate and navigate dynamic situations using tools such as the ISAP to prioritize, strategize, and communicate fire management actions. Importantly, due to the volume of students seeking these qualifications, there are often 5–8 identical simulations occurring at the same time. That is, students are intentionally divided into 5–8 teams (forming ad hoc incident management teams) that they remain with for the entire week. Students fulfill the role on these teams that they are hoping to earn the qualification for once completing the class. This arrangement might provide a unique opportunity to observe and test multiple groups in similarly controlled environments.

We highlight these examples to demonstrate ways to approach assessing DST effectiveness for supporting decision quality. However, this is not to suggest these are the only appropriate methods or the most useful methods of inquiry about wildland fire DSTs. While lab studies are well suited to isolating the impact of a tool in a controlled setting, they are less suited for understanding how a DST might be used in real-life settings. In other words, field-based methods may be a better fit to judge how appropriate the tool itself is for a given environment, and whether the performance of a DST in a controlled setting can translate. After all, wildland fire decision makers often face social and political decision influences that are not incorporated into the design of a DST that may interact, mitigate, or disrupt how a DST adds value or is perceived to be usable (Buettner et al. 2025). For example, the ISAP was designed to help users assess strategic-level risk and facilitate cross-party dialogues to build alignment. However, users described the ISAP could struggle to transparently incorporate social and political factors into decisions—factors past research has suggested are key determinants of wildland fire strategy and therefore critical components to assess if attempting

to holistically assess strategic risk (Calkin et al. 2013; Buettner et al. 2025). These stressors and pressures are likely inherent, but somewhat unpredictable, factors in wildland fire management situations. Field-based qualitative methods (like the studies reviewed) can be leveraged to illustrate the complexity of decision contexts and provide "thick descriptions" of DST use under a variety of conditions (Kostova 2017). Additionally, these methods, when paired with field-based quantitative methods can help construct representations of critical information and support networks and collaborative dynamics that conduct or create social and political pressures that influence DST usage and effectiveness in complex situations.

Because DST research straddles the divide between theory building and applied research, it is not a question of whether researchers should be evaluating DST effectiveness or the contexts within which DSTs are situated, but rather how they can best get at both objectives. Lab-based and field-based research methods, used in concert, offer the opportunity to develop theory-driven, practically relevant insights capable of improving our knowledge of DST effectiveness while simultaneously offering tool improvements in line with DST end user needs.

Conclusion

As DSTs vary in number, sophistication, target audience, and ways in which they are applied across all stages of fire management, there is corresponding interest in understanding how users interface with and apply DSTs to their work. The literature evaluating barriers and facilitators to DST use repeatedly emphasizes the importance of capacity—human, financial, and logistic—in ensuring users have the ability to authentically engage with up-to-date DSTs. These are important findings and key takeaways for those interested in ensuring users benefit from DSTs and do not just interact with them as boxes to check. We encourage DST designers and champions to consider how they envision their DST being used and encourage them to consider the myriad uses identified in the literature, such as information provision, communication, and confidence building and decision validation. While these are important uses, we simultaneously advocate for more attention to the *decision support* part of DSTs. Less developed in the wildland fire DST literature are evaluations of how these tools are affecting decision quality. Looking to the broader body of literature on DSTs in natural resource management, we describe a variety of ways to conceptualize and operationalize DST effectiveness on decision quality based on the form and function of the DST. We highlight criteria for evaluation based on whether a DST is best thought of as an information provision tool or a decision structuring tool. While we provide examples of how these criteria may be applied to RMA and ISAP, there are many tools beyond those examined in current social science for consideration (O'Mara et al. 2024), and tools still under development. The field of DST development is progressing rapidly; it is imperative for our understanding of design principles and our evaluations of effectiveness to develop alongside it.

Acknowledgements
Thank you to the Southwest Ecological Restoration Institutes, and special thanks to A. Kimple and A. Franko.

Authors' contributions
CR: Conceptualization, Methodology, Formal analysis, Writing- Original Draft, Writing – Review & Editing. KC: Formal analysis, Investigation, Visualization, Writing – Original Draft, Writing – Review & Editing. SF: Methodology, Investigation, Writing – Original Draft. MC: Conceptualization, Writing – Review & Editing, Funding acquisition. TA: Writing – Original Draft, Writing – Review & Editing. ASC: Conceptualization, Writing – Review & Editing, Funding acquisition

Funding
Funding was provided by the USDA Forest Service Domestic Grant 22-DG-11132543-086 funded under Section 40803(c)(8) of the Infrastructure Investment and Jobs Act (PL 117-58) and the Joint Venture Agreement FS1500-17b-CSU-JVA-WTO funded by the Infrastructure Investment and Jobs Act (PL 117-58).

Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 23 July 2025 Accepted: 26 March 2026
Published online: 23 April 2026

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