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Use of the Wildland Fire Decision Support System (WFDSS) for full suppression and managed fires within the Southwestern Region of the US Forest Service

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ABSTRACT

Background. United States federal wildland fire policy requires the use of formal decision support systems (DSS) for fire incidents that last for an extended time. However, the ways that wildfire managers use DSSs in decisions regarding fire management remain understudied, including how users engage with or utilise them to make strategic decisions. **Aims.** Researchers sought to understand how users engage with the Wildland Fire Decision Support System (WFDSS), their view of its utilities and challenges, and their perspectives about WFDSS training. **Methods.** We present the results of thematic analysis from 46 semi-structured interviews with employees in the US Forest Service Southwestern Region with a WFDSS user account. **Key results.** Users indicated that the program is viewed as efficient for sharing information about wildfires and documenting management decision rationale. They identified emerging gaps in technical proficiency and the need for specialised training that creates high-level users to help guide teams using the program. **Conclusions.** We offer suggestions about continued use of WFDSS including modifications to information distribution, revision of user roles, and expanded support for skills training. **Implications.** Our results suggest that small changes to the WFDSS program and training curriculum may improve the experience of end-users and better match how they are using the program.

Keywords: decision support, DSS, fire managers, interviews, managed fire, suppression, WFDSS, wildfire.

Introduction

Existing literature recognises that decision making during wildland fire events is inherently complex and uncertain owing to the influence of various environmental, social and political considerations (Jensen 2006; Thompson 2013). The change to a warmer, drier climate, accumulation of fuels in forested ecosystems and expansion of human settlement into combustible wildlands further complicate the wildfire decision environment by promoting larger and more intense fires (Stevens *et al.* 2017; Cattau *et al.* 2020). Choices about when to suppress, steer, or even use wildland fire to achieve resource objectives pose a multitude of potential response alternatives that are evaluated in short time frames, and that often must gain multiple levels of leadership approval as conditions change (Calkin *et al.* 2013). Paradoxically, technological advances such as widespread internet connectivity, advances in fire behaviour modelling, real-time resource tracking or video feeds and social media influences can inundate fire managers with information when making decisions. The result is a critical need to evaluate how end users of technological advances in decision support utilise or struggle to incorporate new information into fire management practices (Rapp *et al.* 2020; Neale *et al.* 2021).

Complex decision-making during natural hazard incidents often relies on the use of Decision Support Systems (DSSs). DSSs combine information derived from multiple sources into a common decision-making environment. They are designed to improve decision efficiency, to provide a process for weighing trade-offs across the objectives present in a complex environment, and to avoid delayed responses during unfolding emergency conditions, all of which can help reduce negative impact to humans and the environment experiencing fires or other hazards (Tufekci 1995; Thompson *et al.* 2006). The research presented here explores the process by which US Forest Service (USFS) fire managers from the Southwestern Region use the Wildland Fire Decision Support System (WFDSS) to navigate the balance between information intake and decision outputs during wildfire incidents.

Despite the widespread use of WFDSS to guide decisions on complex wildfire incidents, there is little research investigating how managers engage with the program or how professionals use it to aid their decision making process. Existing research examining the use of WFDSS by fire managers is limited, and primarily tends to focus on end-user evaluations surrounding specific components of the program. This includes evaluations of information produced by predictive fire behaviour models, comprehensiveness of risk assessment information and case studies of tool use during specific fire conditions, (Calkin *et al.* 2011; Noonan-Wright and Opperman 2015; Thompson 2015; Rapp *et al.* 2020). Others explain the development of the program or discuss generalised impressions that users have towards the program without formal data collection (Noonan-Wright *et al.* 2011; Zimmerman 2011*b*).

DSSs are most useful when they help guide the aggregation of disparate expert judgements or information, reduce uncertainty of decision inputs and help confirm professional experience or intuition (Sprague 1980; Power 2007). However, these findings do not always match the stated purpose of WFDSS to provide optimal decisions that are directly implementable by Incident Commanders (ICs) (WFM-RD&A 2016). Other authors question whether managers are using the program to its full potential in providing detailed trade-offs that lead to resource maximisation (Noonan-Wright *et al.* 2014). Similarly, what little research has been conducted on wildfire DSSs suggests that their perceived utility is contingent on a number of factors specific to the individual, training, or information available in the given context where a fire is taking place (Noble and Paveglio 2020; Rapp *et al.* 2020; Colavito 2021*a*, 2021*b*).

The research presented in this paper addresses research gaps surrounding WFDSS utility for wildfire management using data collected from a range of USFS employees who possess experience with the WFDSS program. We conducted 46 semi-structured interviews with WFDSS users in the Southwestern Region of the USFS. The research seeks to expand existing knowledge about the ways that wildfire managers utilise DSS, how the WFDSS program is currently being utilised for decision making, how users interact in the production of decisions using WFDSS, their experiences with program training, and their suggestions of possible improvements for future iterations of wildfire DSSs. Results from this research could eventually be compared with existing work from other regions of the USA to determine if there are differences in WFDSS use or application across circumstances. Results can also be used to make specific recommendations about the expansion of the WFDSS program, training programs, or evaluation metrics designed to understand how the program interfaces with directorates to improve wildland fire response.

Literature review

Decision Support Systems (DSSs) arose in the early 1980s from concepts related to Electronic Data Processing (EDP) and Management Information Systems (MISs) (Sprague 1980). EDP focuses on the way information is packaged to optimise its use and understanding by decision makers managing larger organisations or hierarchically organised institutions (Mann and Williams 1960). MISs built on EDP-produced data by focusing on the ways that information could be collected or utilised by mid-level decision makers to increase the efficiency of organisation, often by structuring the flow of information or aggregation of data in ways that allow for common understandings among larger, complex organisations (Dickson 1981; Hirschheim and Klein 2012). DSSs aggregate information from EDP and MISs to provide context to the decision-making environment. They often dictate a series of decision considerations or steps for evaluating disparate information using structured rules, weightings, or options in ways that reflect common decision objectives. DSSs emphasise flexibility, rapid use and the ability to respond to differing decision making preferences (Sprague and Carlson 1982).

DSSs are utilised in a wide variety of fields such as clinical medicine and agriculture, as well as in disaster management such as earthquakes, toxic spills and wildfires (Wallace and De Balogh 1985; Sim and Berlin 2003; Keenan and Jankowski 2019). Early DSS developers suggested that DSSs should be designed to reflect a few key propositions: they should be (1) simple so as to be easily understood; (2) robust to the point that they provide relevant and useful answers; (3) controllable so that inputs match outputs in a consistent form; (4) adaptable so that iterative changes can be made as conditions change; (5) complete to the point that the principal factors influencing the decision are included; and (6) easily interfaced with so that the decision evaluation process is not unnecessarily difficult to move through (Little 1970; Power 2007). DSSs can be used help plan response activities during the entire arc of an emergency, including activities for preparedness, training, mitigation, detection, response and recovery (Van de Walle and Turoff 2008). DSSs also possess a common typology, including the availability of integrated data, ability to compare alternatives, the inclusion of models and a user interface that allows the display of information (Wallace and De Balogh 1985; McIntosh *et al.* 2011).

DSSs have been utilised by federal wildland fire managers for several decades (Zimmerman 2011*a*). Early wildfire DSSs used pre-defined, structured decision pathways that fire managers evaluated at various stages of the fire in order to match fire behaviour (e.g. flame length or intensity) to desired fire effect outcomes (e.g. vegetation mortality, scorch height). Some authors described this type of flow-chart DSS as rigidly prescriptive in nature, in part to provide metrics that were justifiable under scrutiny (Devet 1976). The 1978 USFS fire policy revision recognised the need for standardised and more flexible fire decision support tools (Pyne 1982). This led to the development of the Escaped Fire Situation Analysis (EFSA), a form of DSS designed to assist fire managers in determining appropriate wildfire suppression strategy alternatives (Seaver *et al.* 1983). The 1995 National Wildland Fire Policy included direction to update DSSs used during wildfires, leading to the Wildland Fire Situation Analysis (WFSA), which replaced EFSA (Philpot *et al.* 1995; MacGregor and González-Cabán 1999). WFSA was less prescriptive and incorporated greater flexibility in choosing a course of action as long as it supported a suppression strategy (Donovan and Noordijk 2005). Soon after WFSA was developed, the Wildland Fire Implementation Plan (WFIP) and Long Term Implementation Plan (LTIP) were added to the DSS suite in order to provide specific support for long-duration fires managed to achieve a resource objective (van Wagtendonk 2007; Zimmerman 2011*b*). The decision making processes in WFIP and LTIP were determined to require their own DSS tools because Wildland Fire Use (WFU) fires were not intended to be suppressed and thus required different considerations than fires managed predominantly for suppression (National Wildfire Coordinating Group (NWCG) 2005).

The most recent update to DSS used in federal wildfire management came in 2005 when the National Fire and Aviation Executive Board chartered a replacement for all existing wildfire DSSs (WFM-RD&A 2010). This charter directed that the new wildfire DSSs be platformed on the internet, which allows the incorporation of external data sources, incorporates fire behaviour modelling and uses a geospatial interface. The result was WFDSS, which was fully implemented by September 2009 and is the DSS currently used by all federal agencies with wildfire response responsibilities (Noonan-Wright *et al.* 2011).

Completing the WFDSS process results in a WFDSS 'decision'. Federal wildland fire policy requires a WFDSS decision when a fire exceeds initial attack or initial response, or if the fire management strategy includes both protection objectives (i.e. defending structures, infrastructure, or cultural values) and objectives designed to achieve a resource objective (USDI and USDA 2022). The WFDSS decision document is designed to provide the leaders intent of the 'approver', who is the assigned Agency Administrator (AA) for the fire. The WFDSS decision process allows AAs to consider available information or multiple risk factors, determine the scaled complexity of the incident, integrate spatial data and fire behaviour modelling and document a final decision rationale tailored to achieve objectives derived from local land management plans (Noonan-Wright *et al.* 2011). A completed WFDSS decision document typically includes maps, figures, tables and supporting descriptive text that: (1) define the geographic area covered by the decision; (2) assess values at risk given the likely progression of the fire; (3) recommend the Incident Command level that should respond to the fire; (4) provide strategic management objectives for the fire; (5) outline a primary course of action for achieving fire management objectives; (6) outline the rationale for the course of action chosen; (7) provide an estimated final cost of fire management actions; and (8) provide a list of individuals who are capable of approving the decision (Noble and Paveglio 2020). Integrated tools and modules within the program are designed to help facilitate the outputs described above. For additional descriptions of the WFDSS decision process, please see Zimmerman (2012), Taber *et al.* (2013), or Thompson (2015). AA decisions based on the WFDSS decision are intended to reflect long-term fire management strategies, while the IC implements strategies or works with the AA to revise tactics.

Early wildfire DSSs were not formalised throughout agencies and were often localised in their applicability. They also lacked the robustness of computational resources, applied modelling, or a spatial interface that provided operational data relative to potential management actions. For instance, the EFSA was rooted in expected utility theory, where the most appropriate course of action among alternatives is the one that results in a calculated maximum utility for the entity or person making decisions (Tversky and Kahneman 1981; Dimitrakopoulos 1987). The preferred alternative was the one with the lowest calculated Cost plus Net Value Change (C+NVC) over an expected area burned basis (Seaver *et al.* 1983). A maximum utility approach was and continues to be prioritised in many wildfire DSSs or simulation tools because the option perceived as the most risk-reducing is expected to translate into decreased negative wildfire outcomes (higher utility) (Mavsar *et al.* 2013). Studies looking more closely at maximum utility methods have cast doubt on its merit, finding instead a greater prevalence of wildfire decisions where decision makers over-compensate for low occurrence or high risk outcomes (and vice versa), or have their decisions influenced by qualitative factors such as personal affect (Wilson *et al.* 2011; Wibbenmeyer *et al.* 2013). Other authors conclude that highly subjective and varied alternative outcomes in DSSs are driven by the personal judgements of those completing the process (Seaver *et al.* 1983; Dimitrakopoulos 1987).

We found few studies that examine users' general impressions and experience with operating the WFDSS program, which is the aim of this research study. Those research efforts that do focus on WFDSS indicate that the program can be useful to fire managers through the aggregation of disparate information by providing projections of potential outcomes and through fostering dialogue among diverse specialists or resource managers involved in fire management decisions. For instance, both Colavito (2021*b*) and Noble and Paveglio (2020) found that managers appreciated the way that the WFDSS program helps structure the decision process through discrete steps and through the incorporation of various tools such as fire models, spatial data layers, or cost analysis. Completing a WFDSS decision can also increase communication or information sharing among fire professionals and technical specialists, which their study participants indicated had the potential to improve decisions about how best to manage a fire.

Although existing work on DSSs or WFDSSs indicates potential utility, those same studies also note a somewhat complicated relationship between the intent of DSSs and their ultimate use by end users. For instance, results of existing WFDSS and DSS studies suggest that personal attributes of the user (e.g. experience, intuition, trust in model outputs), situational factors (e.g. time constraints, political pressure), or training opportunities for complex programs all influence the ways decision makers incorporate the objective, risk-informed outcomes that a DSS is intended to create (see for example Alavi and Joachimsthaler 1992; Thompson and Calkin 2011; Dulcic *et al.* 2012; Neale *et al.* 2021). The result can be variability in the adoption of WFDSS outputs or use of WFDSS to justify decisions made based on professional experience. For instance, Rapp *et al.* (2020) found decision makers often used fire behaviour models to corroborate their intuition of what a fire would do instead of examining the results empirically to compare alternatives. Meanwhile, Noble and Paveglio (2020) found that WFDSS users appreciate the ability to document their decision rationale and concurrently justify those decisions in the program to alleviate potential liability.

Noble and Paveglio's (2020) examination of WFDSS users in Oregon and Washington focuses specifically on the factors that might lead to variable utility of the program, which matches the intent of the present study. Their results suggest that many fire managers found the WFDSS process complex and time consuming to complete. This was especially true if users were inexperienced or did not use the program frequently. Respondents in Noble and Paveglio's (2020) study reported an overt reliance on staff who were known to be technically proficient in the program, but also recognised that they were in short supply and high demand. Also, those same technical experts were frequently engaged with fire operations and unavailable to assist in drafting the decision document when it needed to be done, leaving a shortage of qualified staff to assist. Training on the use of the WFDSS program was perceived to be of mixed quality, and often depended on the technical skill and teaching quality of the instructor.

The research presented here was designed to expand understandings about the ways the WFDSS program is being used by employees of the USFS. We chose to focus data collection within the Southwest Region of the USFS to capture region-specific attitudes or preferences. Fire season characteristics are generally homogeneous within the Southwest Region, such as an early dry onset followed by a wet monsoon, which makes it a consistent sample frame across National Forests. This region is also known to have an established history of managing wildfires for resource objectives, making it an ideal location to investigate how WFDSS is being variably used across full suppression and fires managed to achieve a resource objective. The following research questions guided our research WFDSS within the Southwestern Region of the USFS:

1. How is WFDSS used in the fire incident decision making process?
2. What is the perceived effectiveness of WFDSS training modes?
3. How do fire managers use WFDSS differently when developing decisions for full suppression and when considering fires managed for resource objectives?

Methods and analysis

The sample frame for this study included employees of the USFS who possessed an active WFDSS user account and who were employed within the USFS Southwest Region, also known as Region 3. This region comprises National Forests and Grasslands in Arizona, New Mexico and portions of Texas and Oklahoma. We chose to focus on the USFS because it is the federal agency with the most active users of the WFDSS program. We sampled within Region 3 because National Forests there experience frequent large fires and because fire managers there are known to regularly manage wildfires to achieve a resource objective (Young *et al.* 2019; Iniguez *et al.* 2022). Selecting users from Region 3 also allowed the authors to assess perspectives surrounding WFDSS in additional USFS Regions, as Noble and Paveglio (2020) studied the Pacific Northwest Region.

Contact information for all potential study participants was downloaded from WFDSS directly with permission from the Wildland Fire Management Research Development & Application (RD&A) program that oversees and manages the WFDSS program on behalf of all the agencies. Initial sample frame development resulted in 368 potential users for the study. Researchers (i.e. the authors) employed a stratified random sampling approach similar to Noble and Paveglio (2020) to further ensure representative perspectives across our sample frame (Babbie 2004). More specifically, we organised potential participants according to one of the five user roles in WFDSS to ensure representation across all user role classes. WFDSS roles in ascending order of accessibility privilege are: Viewer, Dispatcher, Author, Fire Behaviour Specialist and Geographic Area

Editor (see Noonan-Wright *et al.* 2011 for a descriptions of these user classes). We assigned potential participants to the category that reflected their highest authorised role if more than one role was listed. Each of the five users class lists was copied into Microsoft Excel and then assigned a randomly derived number identifier. The researchers randomly selected participants from each strata (i.e. user role) for potential interviews to maximise representation across user roles. Table 1 provides a breakdown of the participants listed by user class expressed a percentage of the whole.

The USFS Southwestern Regional Office distributed an introductory email notifying staff about our study prior to initial contact. Our first contact method was to send a personalised email that included the individual's random number ID and instructions about how to sign up for an interview time in a private cloud-based scheduling tool. Other interviews were arranged verbally or through email communication. If no response was gained from the initial email, we attempted contact up to two additional times at varying time intervals and via multiple, non-repeating modes of communication (e.g. a phone call, followed by USFS direct-messaging software). After three non-responses, we moved to the next potential participants on the list. We continued the process of recruitment and interviewing until theoretical saturation across user classes of the sample frame was achieved. Theoretical saturation occurs when researchers agree that no new major themes or ideas are becoming apparent from subsequent interviews (Bryman 2015).

The SARS Covid-19 pandemic affected both the contact process and our interviewing methodology. Our initial research plan was to conduct most interviews in person. However, pandemic-related travel restrictions and stay-at-home orders forced interviews to be completed via telephone or video teleconference. Interviews began on 24 February 2020 and continued through 17 March 2020. At that point, we were forced to suspend data collection for a period of time during the height of the pandemic owing to work-from-home orders at federal agencies as well as social uncertainty. Interviews resumed on 5 May, and we completed data collection on 30 July 2020. In total, we attempted to contact 131 individuals at least once. Of the 131 potential respondents, 21 were excluded after we discovered they did not meet the inclusion criteria (e.g. they had retired or moved out of the Region). Approximately 46 responded to our contact attempts, of which all 46 agreed to be interviewed.

Researchers (i.e. the authors) created a semi-structured interview protocol to guide data collection. Semi-structured interview protocols allow consistent questions to be asked of all respondents, but they also allow researchers to propose follow-up or probing questions that allow for the emergence of novel ideas (Patton 2002; Bryman 2015). Interviews lasted between 27 and 88 min and averaged 52 min in length. Interview participants spanned all 11 National Forests and Grasslands in Region 3 as well as the Regional Office. We interviewed users from all available roles except for Geographic Area Editors, of which only two exist in the Region (one contact attempt was non-responsive). Participants occupied a broad range of positions within the USFS including AAs, fire management staff, dispatchers and dispatch supervisors, module-level firefighters, biologists, rangeland staff, planners, recreation staff and support service staff. All telephone interviews were recorded using the NoNotes application. Interviews on Microsoft Teams video teleconference software were securely recorded within the program. All interviews were transcribed verbatim for later analysis.

Data were analysed using the QSR Nvivo 12 qualitative coding software (QSR International 2022). We utilised an iterative, inductive and multistage coding process guided by principles of thematic analysis and analytic induction (Boyatzis 1998; Ryan and Bernard 2000). Thematic analysis focuses on identifying commonalities in the experiences articulated by research subjects, while analytic induction provides a systematic process for deriving causal explanations of that shared experience through comparison across individual respondents.

Coding took place in three increasingly restrictive phases, with each phase representing a separate 'read' of the data

Table 1. Distribution of WFDSS users classified by user role.

Distribution of WFDSS users in Region 3			Distribution of WFDSS users within study participants		
	No. of users	%		No. of interviews	%
Dispatchers	17	4.62	Dispatchers	5	10.87
Viewers	137	37.23	Viewers	17	36.96
Authors	188	51.09	Authors	18	39.13
Fire Behaviour Specialist	24	6.52	Fire Behaviour Specialist	6	13.04
Geographic Area Editor	2	0.54	Geographic Area Editor	0	0.00
Total	368		Total	46	

Distributions are reported by the total number of users within the Southwestern Region (R3) and the distribution of study participants. Regional numbers were current as of 23-Dec-2019.

and discussion about consistency among the researchers to ensure reliability. A first phase of 'topic coding' assigned a primary topic to each distinct segment of respondent dialogue in the interview transcript (Richards 2014). Researchers independently coded interviews at regular interviews, reviewed topic codes and discussed any inconsistencies until there was shared agreement about the coding strategy (Strauss and Corbin 1990). The second round of coding employed 'descriptive coding', which looks within topic codes to inductively identify patterns in the perspectives or experiences articulated by respondents (Richards 2014). Researchers periodically reviewed their independently generated descriptive codes that were emerging across data and discussed any inconsistencies to ensure reliability (Gibbs 2007). The final stage of 'analytic coding' allowed us to identify consistently occurring themes within the experience of WFDSS users. It also helped identify consistent relationships among the descriptive codes articulated by respondents, including any similarities or differences among respondents (Saldaña 2016). Finally, researchers jointly selected representative quotes associated with analytic or descriptive codes to aid in presentation of results in subsequent sections.

Results

The WFDSS decision making process

Interviewees described a fairly consistent decision making process associated with the WFDSS program. Decisions were frequently produced and finalised in a small group setting, which interviewees often compared to 'Interdisciplinary Teams' (IDTs) that are used to develop National Environmental Policy Act (NEPA) analysis documents (see Cerveny *et al.* 2011 for an example). Small groups completing a WFDSS decision typically included the delegated AA, fire management staff, natural resources specialists and the fire IC.

Interviewees indicated that WFDSS decision groups typically came together within a day of the fire starting, though there was some variance based on fire behaviour and any associated need for risk management. For example, if a fire was displaying low fire behaviour activity and was tentatively going to be managed to achieve a resource objective, the decision making group often chose to delay the WFDSS development meeting to allow for more preplanning. Interviewees indicated that teams would be better prepared for such longer-term fire events by crafting a deliberate and thorough WFDSS decision. Conversely, fires that were being actively suppressed, especially those with high fire behaviour activity and the potential for rapid spread, led to more immediacy in the completion of WFDSS decisions even if it required working late into the night. This was especially true if an Incident Management Team (IMT) was needed. One interviewee described the difference this way:

> The timing on these things is very short, almost impromptu, because the fire is continuing to spread, and we need to know whether we're going to suppress or allow it to grow, and it usually happens pretty quick.

Participants indicated that that the most desirable outcome of a WFDSS decision was consensus about the next steps for managing the fire. They also acknowledged that the first decision created in the program may not be the best possible outcome, stressing that WFDSS allowed for iterative refinement over time as conditions changed. Likewise, participants described a general sense of aversion to putting extremely detailed information into an initial WFDSS decision. Some even suggested that the appropriate strategy was to 'publish first and refine second' instead of trying to get it perfect the first time. One AA described their perspective this way:

> It doesn't take us very long here on the unit to publish a decision. I think if we're over two hours, then we're not doing something right. Even midnight or whatever, but we definitely strive not to do that… I mean, you can always adjust it.

Internal conversations that occur during the WFDSS decision process were seen to have unique value. Staff who worked within a natural resource specialty (e.g. biologists, archaeologists) reported that these conversations allowed them to feel like their feedback regarding the fire was going to be included in the ultimate decision. Natural resources staff and other casual users indicated that they predominantly logged onto WFDSS to obtain basic information related to wildfires, including where the fire was located, the current fire perimeter, intended location of control lines and fire modelling projections so they could inform the fire managers about values that might be at risk. Both user groups found particular value in the provision of timely and accurate information to ensure that concerns were both known and addressed. Some users suggested that conversations occurred among natural resource and fire staff regardless of the WFDSS requirement. However, they articulated that a structured approach helped to facilitate these interactions more regularly. One natural resources specialist saw their experience with collaborating on WFDSS decisions this way:

> Does that mean that every specialist leaves happy? No, but that's not the point. The idea is to get all the information from all of us, so that the decisions can be made. And obviously when it comes down, timing is going to be the first thing. So, from what I've seen, it looks like it balances it pretty well. It takes in account risk from all sides.

There was no clear 'right way' offered in which to conduct the WFDSS decision making process. Instead, participants described how personal preference and comfort with known decision making pathways informed the various approaches teams or individuals took to complete decision documents. Moreover, users saw this flexibility in approach as a strength of the program, allowing the way decisions were made to be adapted to the current fire conditions and timeframes. For instance, although the vast majority of participants described working in a small group setting towards a decision document, some AAs preferred to complete the WFDSS decision on their own, with only limited input from their staff. In other cases, teams might conduct a series of meetings with staff from different specialties (e.g. wildlife biologists, recreation specialists) to incorporate their expertise and inputs. Some interviewees suggested the latter approach helped mitigate WFDSS users from being overwhelmed, and ensured that all staff areas had equal representation in the decision.

Regardless of the process used to carry out WFDSS, participants acknowledged a tendency to rely heavily on an increasingly concentrated and shrinking pool of 'WFDSS drivers'. Drivers take on the actual task of entering data and interacting with the WFDSS program. These drivers were viewed as a critical resource and the small group of trusted WFDSS drivers were often mentioned by name among interview participants. The shrinking pool of WFDSS drivers was alarming to our interviewees, as the demand for their skill set was seen to be increasing owing to changing fire conditions and the complexity of running the program. One participant described the situation as such:

> I don't feel like we have enough depth, and that's another fault. We maybe have two people that are super good at WFDSS here. I think for the complexity of this Forest and the size of the Forest, it's not enough, and we could use more depth, more training for sure. No question.

Participants described the spatial interface as the most information-rich and easily accessible attribute of WFDSS. The intended use of the interface is to delineate strategic spatial features such as management action points, planning areas, known perimeters, or contingency lines. Respondents indicated that spatial outputs or capacities in WFDSS related to fire behaviour modelling were a helpful way for managers to validate decisions and courses of action. They stressed the value of preloaded spatial data in WFDSS that were strategically relevant and accurate for helping the decision making process. For instance, respondents indicated that the most valuable data layers were nationally managed products such as fire history perimeters, property boundaries and infrastructure of national significance. However, data layers that were site specific such as archaeological or sensitive biological sites were often seen as less available or outdated, often because local data managers were unable to keep up with maintaining the accuracy or recency of spatial data. This had the potential to cause confusion among users, as one of our interviewees related:

> One of the conversations I haven't really heard happen is that it seems like a lot of stuff gets preloaded in there. And when I've asked the question of who does it, it's always like, oh, the [Regional Office] did, or the Washington Office or whatever, but we end up with some of the weirdest layers and some of the oldest, most outdated stuff in there. And again, that could be a miscommunication on my Forest side of not knowing what to do with some of that.

Participants also described challenges integrating more complex data sets or supplemental information in the WFDSS program, including Potential Wildfire Operational Delineations (PODs) (Thompson *et al.* 2016, 2022). They described loading PODs into WFDSS as an arduous task they would like automated or maintained at a higher organisational level.

Validating WFDSS decisions

Participants reported that while WFDSS assisted their wildfire decision making process, the function of the program was not to make the decisions for them. Users broadly agreed that decisions such as the course of action, response strategies and incident complexity levels should be retained by human decision makers. In this capacity, WFDSS was described variously as a 'laundry list', as a reminder for items needing assessed, or as a guide for bringing the decision process to fruition. For instance, one user described the program as such:

> It helps, as I said before, it's not a decision maker, it's a decision support tool and so having a decision support tool that is … consistently used by land managers helps us to be more consistent in our decisions that we actually make… there has to be room for professional judgment and experience in actually making the decision. But I like the fact that we have this sort of a standardised approach to ask the right question.

Interviewees described WFDSS as an important mechanism to document the actions and decisions made as wildfire incidents evolved. It could allow decision processes to be traced and understood in the event of adverse outcomes such as the loss of life or property. The results of this documentation could include an ability to learn about alternative decisions that might have been made during the event or to alleviate liability of the decision maker. Others indicated that decision documentation could be used as a frame of reference to assist with administrative tasks such as cost apportionment. Hence, users reported WFDSS as providing both a way to contemporaneously document the rationale leading to the final decision and provide a strategic course of action for others to read. One interviewee described the importance of documenting decisions in WFDSS this way:

> And the ask that they had, it was that we document our decisions and the rationale for the risks that we were taking, so I basically just took that seriously. And I feel like since it is a life-and-death thing, and since it's involved with hundreds of thousands or millions of dollars, that I owe the taxpayer or anyone that wants to look at it as an explanation for what I'm doing. And so, I guess it's just kind of a sense of duty in part.

Although outputs such as the suggested organisational complexity level are rigidly expressed in WFDSS, study participants had varying opinions on how close these recommendations should, or needed, to be followed. Likewise, they indicated that fire managers may base decisions on preconceived notions of fire risk ratings or personal experience rather than using outputs of the decision process that is built into the WFDSS program. For instance, users described deviation from WFDSS outputs for the relative risk rating of the fire (which determines what risks are present and how complex they are) and organisational assessment (denotes the type of incident management organisation required), especially when the program recommendation was on the borderline of complexities. Decision makers wished to retain the ability to either take the route of caution and order a higher-level IMT or manage the fire at the local unit level if they believed that they could handle it. Experienced fire managers were the most transparent regarding their comfort in 'gaming' WFDSS to match their experience, which they regarded as more nuanced and responsive than the WFDSS outputs. Similarly, most AAs desired to retain this scope of authority. They described being comfortable constructing a rationale to support decisions they made, and desired to retain their authority to deviate from WFDSS when they felt it was necessary. One AA described their view this way:

> I see people really stressed out needing to defend why they want to do something different than what WFDSS is telling them. I'm just not in that place. I'm a selector of information and we make our own decisions.

However, caution was also expressed when decision makers chose to deviate too much from suggestions made in WFDSS for fear that any negative outcomes arising from the fire could be traced back to their overriding the recommendations the program provided. As such, respondents who were commonly tasked with helping to assess risk articulated that more time should be spent exploring risks that were specific to the current fire. They also expressed a desire to have a more deliberate focus on user input of narration that explains how risk ratings were derived, especially if clear deviations from WFDSS outputs were incorporated into the final decision.

WFDSS training and help

Interview participants indicated that the annual 'WFDSS refresher' conducted by individual Forests provided an important and often initial training in the use of WFDSS. The refresher provided instruction on the general use and intent of the program, but was not necessarily formalised training. Both users and providers of these refreshers agreed that the WFDSS refreshers were not sufficient for developing the skills necessary to become an independent WFDSS driver. Likewise, few participants were aware that detailed training materials existed online or knew for certain that a WFDSS Help Desk existed; however, there did appear to be a general awareness that there was an online WFDSS training site available. As one WFDSS author described with regard to refreshers:

> I think we're more like introducing them to it, we're not expecting a whole lot. I think just exposing them to the process, to understand that fire is a lot bigger than just the operational side. There's a lot that goes into it, so it's good for them to know so they can help convey that information to whoever's doing it.

One way the refresher training could be helpful was in understanding how diverse professional expertise was integrated into the decision making flow of the program. For example, resource specialists such as archaeologists, recreation staff and biologists described how the bulk of their input was required early in the decision process to properly inform the values-at-risk analysis. Specialists reported that the WFDSS refresher and other entry-level training about WFDSS helped clarify the type and quantity of information most relevant to the WFDSS decision process. This allows an efficient incorporation of information without over-analysis under time limited conditions.

The preferred mechanism to learn about WFDSS was live, in-person training, as this would allow participants to fully concentrate on the training session. Participants expressed reservations about video teleconferencing or virtual training, as such environments might include the distractions of their regular work like attending to email, conversations with co-workers or the need to accomplish other tasks. Virtual classes also were viewed as a difficult setting in which to interact with classmates or ask clarifying questions of trainers. Select participants did provide examples where virtual training had been effective. Those trainings featured well-structured scenarios, a mix of instructor-led and self-directed learning, and the ability to obtain direct help from instructors. Regardless of the training mode, participants saw value in the ability to utilise WFDSS using a variety of hypothetical scenarios during training sessions. They described how the ability to ask questions or experiment with the program during these hypothetical fires could help develop their proficiency with the information and decisions the program would provide during real world fire incidents.

We observed that perspectives on training somewhat diverged based on the individual user role in WFDSS. Those with dispatcher or viewer roles tended to be only lightly engaged with the WFDSS process and might not be directly involved with the program besides supplying initial information. These users did not see the need to possess any technical ability in using WFDSS beyond the basics such as logging in and navigating between pages. They felt it was more important to know how the components and technical information were integrated into the eventual decision. WFDSS 'drivers' reported a greater desire to be technically competent in the workflows of the program. Although this group is not usually a part of the decision making process, they often serve as a skilled guide to help others navigate through the process. Users who sought to become proficient using WFDSS, usually those with an author role, described two primary ways to learn the program. The first way was through one-on-one training with a skilled user, often during actual fire incidents. Others described undertaking a self-motivated path of independent learning reinforced by occasional opportunities to use WFDSS during actual fires.

WFDSS drivers valued rapid access to help when needed. They expressed a desire for specialised, task-focused online help, for instance, a short explanatory video on importing photo files into decision documents. The official WFDSS Help Desk and online training tutorials were frequently mentioned as important sources of help. Participants tended to call someone when they needed help immediately and used the help desk or online resources when time pressures were less present. In that regard, the video and written tutorials were mentioned as a means to support the self-directed training users described above.

WFDSS and wildfires managed to achieve resource objectives

Participants described finding greater value in the WFDSS process when fires were expected to burn for extended periods of time, and particularly during managed fires where the strategy was to achieve a resource objective in addition to protection objectives. The planning tools within WFDSS allowed users to plan for potential control lines, values at risk in both short- and long-term timeframes, and potential fire effects over time. One participant described the importance this way:

> Line officers are interested in whether to … try to get a good idea of potential effects. So, if we're looking at hotter fire for the next 2 months, they're considering what's that going to do to the timber stand out there. Reduce stand density more than what we would hope for, or is it going to be so cool and calm that really, we're going to just create smoke and not really change the stand to move toward the desired condition, so that it may or may not be worth taking something on?

Interviewees reported less value in suppression-oriented WFDSS decisions as those tend to follow simple strategies, and little cross-disciplinary planning is typically required. One author discussed their role as an IC on managed fires:

> Well, that's what's nice about using WFDSS when we're doing management fires, we can actually jump in when the acreage is small. So, we usually start the next day, or Day 3 or 4 [after the fire ignites], after we've made our plans and stuff and kind of drawn in our blocks, and determined where we're going to have to fire at… so let's say within three operational shifts, that's when we start using it. I've never dealt with it for suppression.

The interdisciplinary decision development process that users commonly employed to complete a WFDSS decision did not appear to differ between suppression and managed fires. However, participants did report that the time frames under which WFDSS decisions were created for each condition could vary greatly. Fires managed with a suppression strategy came with pressure to complete a WFDSS decision as quickly as possible. This reflected users' perception that if a large number of values were at risk, a fire should be suppressed, and a rapid response was needed. Conversely, values at risk might not be the principal influence on fire management decisions. Participants indicated that in these instances, decision making groups could take more time to work through the decision process and build a comprehensive plan that addressed as many concerns or values as possible. The longer-term planning approach, facilitated by WFDSS during managed fires, also allowed for external discussions with affected parties. For instance, livestock producers supportive of managing fires for resource objectives did not wish to see their fences damaged during fires. Another common example was the need to talk with nearby communities who might be concerned about potential impacts from smoke or the fire itself. Participants indicated that the result of taking more time in the up-front planning process, including early and continuing conversations with affected parties, allowed a comprehensive understanding of the values at risk and better protection strategies for valued resources such as fences, cabins, or vulnerable archaeological resources.

Discussion

The purpose of this research was to explore how a regional subset of USFS employees are utilising the WFDSS. We were interested in better understanding users' experiences with the program, including its perceived effectiveness, and the provision of training or help in the use of the program. We also explored participants experiences' using WFDSS during fires that were being managed with a strategy other than full suppression, which has not been well explored elsewhere in the literature. We found that WFDSS users often utilise the program to document or inform the decision making process rather than to guide ultimate decisions, which is consistent with some other recent studies on the topic (Noble and Paveglio 2020; Rapp *et al.* 2020). Users do see utility in the program for integrating various perspectives or in documenting rationale, but they also maintain that the program and its uses should be flexible given the situation encountered during each fire (e.g. available personnel, resources, fire conditions), which can influence how much the program actually informs fire management decisions. This reflects a continued interest in valuing the professional experience of managers while using WFDSS to make decisions. 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. We also found that in the Southwestern Region of the USFS, participants saw utility for WFDSS during fires managed for objectives other than full suppression.

Participants in this study made it clear that DSSs such as WFDSS serve important roles in wildfire management despite the work, time and effort required to complete a decision. WFDSS was seen as useful because it can help guide or provide input to the decision process or improve communication and documentation of the decision rationale as the incident evolves. The result, according to our participants, is more efficiency among fire professionals attempting to reduce potential damage to values at risk. Although the WFDSS program was seen as assisting decision making, it was not viewed as a tool that could or should dictate decisions without some application of critical thinking from a broader decision making group. Those findings reflect foundational DSS literature, including Sprague (1980), who recommends that DSS be used for decision support when the problem is unstructured, which is often the case during wildfires (Castellnou *et al.* 2019).

Participants rarely suggested that the outcome of a WFDSS analytic process should be the 'final answer'. Instead, they often felt that WFDSS was a guide to be corroborated by their own experience. Use of WFDSS as a decision input is consistent with findings from Noble and Paveglio (2020) and Colavito (2021*b*), both of whom found that strategic decisions about a fire were often made prior to undertaking the WFDSS process, thereby making the exercise more akin to a decision documentation process. Similarly, Rapp *et al.* (2020) found decision makers often used fire behaviour models to corroborate their intuition of what a fire would do instead of examining the results empirically to compare alternatives. Neither of these outcomes are the original intent of WFDSS, which was designed to guide decision makers through a step-wise process of evaluating alternatives, risk and potential courses of action.

Although our participants did not want decision authority to come solely from the WFDSS program, there was very little discussion related to how much emphasis or responsibility should come from professionals using WFDSS. Likewise, there was less clarity about how outputs from the program should influence a range of manager decisions. Instead, participants indicated that decisions based in part on WFDSS outputs were still dependent largely on professional judgement, with variation among decision makers in terms of how they valued the information from WFDSS or how they utilised IDTs to arrive at a rationale for the ultimate course of action. Similar dynamics were observed in Noble and Paveglio (2020) and are noted in other DSS literature (e.g. Alavi and Joachimsthaler 1992; Neale *et al.* 2021). Future research should explore this 'grey area' of professional judgement in wildfire decision making by exploring users' trust in or use of specific quantitative outputs from WFDSS. That exploration could also incorporate explicit comparison across USFS regions to uncover whether and how managers in different areas of the country conceive decision support from the program. Special emphasis could be placed on how and whether various outputs from the WFDSS program help inform judgements made by professionals, their role in reducing uncertainty related to the fire environment and whether they uphold or contradict their professional experience as the complexity of the incident unfolds. Results from these more specific efforts might help extend theory surrounding DSS integration as a part of cognitive processes for managing risk and provide specific recommendations about which components of the WFDSS program need revised outputs or additional substantiation.

Our results suggest that managers often apply the existing practice of using small interdisciplinary teams (i.e. specialists and technical experts) for land management planning efforts when approaching the use of WFDSS. This approach also was apparent in WFDSS studies of other USFS Regions (see Noonan-Wright and Opperman 2015; Noble and Paveglio 2020). Although using the IDT process is mandated by policy within the context of NEPA (Stern and Predmore 2012), there is no policy-based direction on how to complete a WFDSS decision. Therefore, emulating the use of an IDT during WFDSS may serve as a form of organisational heuristic, especially as WFDSS decisions are often completed in a time-compressed context. We would suggest that the preference for using small IDT teams to complete a WFDSS can serve as an important acknowledgement and strategic opportunity in the continued use of the program. Likewise, use of IDT teams to complete WFDSS might open up opportunities to discuss trade-offs in tactics, resources affected, or managed fire use. Working through scenarios for fire impact and response, and their application in particular contexts may also increase the amount of trust and comfort among specialists and decision makers tasked with applying WFDSS to improve operational efficiency. Trust and experience in collective decision making are both noted as important influences on effective DSS use in uncertain environments (Fröhlich *et al.* 2022) and also appear to have helped facilitate the use of managed fire for resource objectives to the extent seen in Region 3, despite being a course of action that can carries considerable risk (Canton-Thompson *et al.* 2008; Calkin *et al.* 2011).

We observed three functional roles articulated by WFDSS users in this study: (1) data managers who were also advanced authors or fire behaviour specialists; (2) 'authors' who possessed technical competency with the WFDSS program; and (3) peripheral viewers who only sought information. This arrangement seems to have arisen organically as managers learned efficient ways to arrive at a final decisions and processed adapted to realities. From a decision hierarchy standpoint, decision makers seemed to value having access to a pool of experts from which to receive counsel and avoid liability, and another (smaller) pool of experts to simply run the program in a way that reflected their decision making process. Also, organisational process changes influenced how user classes interacted with WFDSS. For example, the recent introduction of the Integrated Reporting of Wildland Fire Information (IRWIN) program altered dispatching workflows in a way that eliminated the need for dispatchers to directly populate WFDSS.

Our results suggest that WFDSS utility extends to fires that are managed for objectives other than full suppression. That is, participants in this study indicated that naturally occurring fires in the region were often managed with a strategy other than full suppression, and that WFDSS outputs helped support those choices through forecasting the conditions where the use of wildland fire could achieve a resource objective. This positive link between WFDSS use and managed fire has not been reported in earlier research on WFDSS, though it was consistently expressed in this research across multiple Forests and employees, ranging from Forest Supervisors to Engine Captains to natural resources staff. Thus, our results suggest that there may be opportunities to explore additional tools, training, or considerations related to the WFDSS decision making process that support beneficial use of managed fire. Notably, WFDSS does not contain any tools specifically designed to assist decisions for managed fires; rather, tools within it are leveraged in the same way as in full suppression fires. Integrating emerging guidance such as the Managed Fire Decision Framework discussed in Fillmore *et al.* (2021) (or other similar tools) into fire risk analyses during managed fires may help to inform a more comprehensive understanding of the factors that decision makers used while constructing the WFDSS decision. For example, the six key decision factor themes identified in Fillmore *et al.* (2021) (fire environment, fire outcomes, operational considerations, socio-political factors, institutional factors and perceived risk) could be incorporated as factors influencing the relative risk rating and organisational assessment function of WFDSS. The result would be a mechanism for identifying influences on decisions made under all wildfire strategies.

Program conclusions and recommendations

Managers in the Southwestern Region do not appear to be using the WFDSS program for the explicit decision guidance that was originally intended at the onset of the system. Instead, our results suggest that WFDSS is largely being used as an information source for peripheral users or an archivable location for decision documentation. It also appears that the WFDSS user base is self-selecting into either specialists or generalists, with the former consolidating expert-level skills, and the latter primarily contributing information during the WFDSS decision making process. Although this emerging paradigm does not seem to present any operational barriers, the number of individuals who are technically skilled in operating WFDSS is universally seen as few and declining. In response, the USFS might consider deliberately expanding and promoting a widespread user base that possesses high technical competency with the WFDSS program to maintain an adequate pool of competent WFDSS 'drivers'. Our research found that there was an untapped reservoir of capable staff willing to increase their involvement with WFDSS, but they will need those duties to be explicitly acknowledge in their position descriptions or to be freed from other responsibilities to serve as 'drivers' on an increasing number of fires in the region.

The WFDSS pool of expertise could be expanded by offering mentoring-based training spanning units and capitalising on highly experienced WFDSS users in units with frequent fires. One potential route for enabling mentor-based training could be to annually solicit volunteers who want to improve their skill levels and contribute. WFDSS driver 'trainees' could have additional training added to their position description for the year and be paired up with a mentor who could assist their development remotely, or through on-the-job training during fire incidents in home units of the mentor. Mentor-based training would most likely be facilitated or coordinated at the Regional level of the USFS because Regional staff would have a better understanding of their available pool of trainees and strategically use it to augment capacity in units with more forecast fire. From an administrative standpoint, this type of mentoring-based development program is similar to the existing taskbook-based qualifications system already used extensively by firefighting staff and AAs (USDI and USDA 2022).

Strategic responses to the process flow and emergent user classes we catalogued in this research might also improve overall utility of the WFDSS program. For instance, future iterations of WFDSS might follow a similar binning of roles we found in this research, whereby 'data managers' integrate, catalogue or curate WFDSS data; 'authors' can function as a 'driver' of the program during fire events and by drawing in quality data from 'data managers'; and 'viewers' can observe or query data from the program without requiring the technical skills to run the entire program. Alternatively, the agency could develop a public-facing website that displays WFDSS-derived data, thus eliminating the need for a viewer role or passwords. We suggest removing the 'Dispatcher' role altogether.

Finally, we recommend tailoring WFDSS training to more explicitly reflect the level of engagement users have with the program. For instance, although most training is completed at the local or Regional level, a more tailored refresher training for decision authors (i.e. 'drivers') could be more akin to the RT-300FS 'Burn Boss' refresher training, or other wildfire-based refreshers such as the RT-130. Such author-focused training could incorporate case-study examples of WFDSS use from real fires, mechanisms to efficiently facilitate arriving at a decision across the range of AA decision making style preferences we uncovered in this research (e.g. small group, collating information) and hands-on experience that is accompanied by feedback from experienced users. Conversely, WFDSS training tailored toward those who contribute information to decision makers or WFDSS drivers may be better served with a curriculum designed to illustrate the kinds of information that may be requested of them, how to best provide that information to maximise WFDSS utility, or the level of detail necessary given potential time constraints. Thus, we would suggest that training surrounding WFDSS be disaggregated and become more specialised to reflect the self-organising and team-based use of the program in order to further improve its integration into the decision making environment surrounding wildfire management. Varied curriculum would allow respective users groups to better concentrate and excel at what is expected of them during a wildfire incident.

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