Exploring Adoption Success of the Wildland Fire Decision Support System

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Authorization to Submit Thesis

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Abstract

Increases in wildland fire frequency, size and duration have increased the threat of wildfire impacts to human and natural resource values and strained wildland firefighting resources. The increasing complexity seen in wildland fire management has highlighted the importance of sound decision making based on best available science. Numerous fire management decision support systems have been developed to enhance science and technology delivery and assist fire managers with decision-making tasks. However, no scientific efforts have evaluated their adoption by fire managers. Drawing upon decision support system implementation research and in-depth interviews with U.S. Forest Service fire managers, we explore their perceptions regarding the Wildland Fire Decision Support System (WFDSS). Although fire managers appreciate many of the components of WFDSS, they view WFDSS as primarily useful for documenting fire management decisions and often experience on-the-ground actions that are disconnected with decisions developed or documented in WFDSS. Fire managers furthermore attribute these concerns to factors related to the timeliness of WFDSS outputs, the complexity of the WFDSS design, and the manner in which WFDSS was implemented. We discuss how these challenges may be addressed by improving training and top management support for WFDSS as well as better matching WFDSS capabilities and complexity to fire manager needs and abilities by increasing the user-friendliness of WFDSS and supporting more proactive decision support tools. We conclude by describing how future efforts to develop FMDSS may benefit from this research as well as the broader literature surrounding DSS implementation.

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Dedication

This thesis is dedicated to my amazing family and friends for their unending support in my life, and to the extraordinary men and women in the wildland fire service with whom I have had the privilege to work alongside.

I am deeply indebted to my family, and especially to my parents, James and Kathy Noble. They have been constant source of love and support in my life and have made enormous sacrifices in order to encourage my education, support my interests, and provide a grace filled home in which to grow up. I thank the friends I found in Moscow who made my time at the University of Idaho immeasurably richer and shared with me the joys and sorrows of the grad school experience. I will forever treasure the memories and friendships made through late evenings at coffee shops and early mornings adventuring in the mountains. Finally, I would like to recognize the many incredible firefighters I have worked with who have inspired me to be a "student of fire." I would especially like to acknowledge the leadership and crewmembers of both Skyway Wildland Fire Module and Kings Peak Wildland Fire Module for their understanding and support over the past three years as I rushed between school and fire season. Ultimately, it is my hope that this research would contribute towards the safety and effectiveness of those who engage in wildland fire management.

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CHAPTER ONE: Exploring Adoption Success of the Wildland Fire Decision Support System

1: Introduction

Wildland fire management is one of the most challenging issues that land management agencies face (Noonan-Wright et al. 2011, Zimmerman 2011). Climate change, fuel accumulation stemming from historical fire exclusion, and the expansion of human development into or interspersed with wildland vegetation (the Wildland Urban Interface) have all contributed to longer fire seasons and more large severe fires that pose increasing threats to a range of ecological and socio-economic values (e.g. endangered wildlife habitat, residences and infrastructure, air quality) (Brown et al. 2004, Bruins et al. 2010, Dennison et al. 2014, Mell et al. 2010, Schoennagel et al. 2004, Thompson et al. 2012, Westerling 2016, Morton et al. 2003). Average annual costs for federal fire management have increased significantly since 2000 while funding for fire management agencies and the associated number of firefighting resources have remained relatively unchanged (GAO 2007, Pence and Zimmerman 2011). As a result, fire managers are under increasing pressure to make timely and complex fire management decisions surrounding public protection, firefighter safety, and land management objectives in an environment characterized by incomplete information, resource scarcity, and an emphasis on reducing firefighting spending (Noonan-Wright et al. 2011).

Federal wildland fire policy identifies risk management as a key element of wildland fire decision making and states that "risks and uncertainties relating to fire management activities must be understood, analyzed, communicated, and managed" (USDI, USDA 1995 pg. 4). Risk-informed decision making for wildland fire incidents focuses on selecting economically appropriate fire response strategies based on the identification and assessment of risks to public and firefighter safety as well as positive or negative fire impacts to resource values (Calkin et al. 2011). Prior to 2009, federal wildland fire management agencies (e.g., U.S. Forest Service, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and Bureau of Indian Affairs) utilized numerous fire management decision support systems (FMDSS) and stand-alone fire behavior modeling programs to assist managers with developing risk-informed fire management decisions. Examples of FDMSS used by federal agencies during this time period include the Wildland Fire Situation Analysis (WFSA), the Wildland Fire Implementation Plan (WFIP), the Long Term Implementation Plan (LTIP), and the Strategic Implementation Plan (SIP), while standalone fire

behavior modeling programs include BehavePlus, FlamMap, FARSITE, and FSIM (Noonan-Wright et al. 2011, Pacheco et al. 2015).

Federal agencies adopted the Wildland Fire Decision Support System (WFDSS) in 2009 as a streamlined decision support and documentation tool applicable to all wildland fire events at all scales (NWCG 2009, Noonan-Wright et al. 2011). The adoption of WFDSS stemmed from updated federal fire policy guidance that recognized the inefficiency surrounding the use of multiple FMDSS and mandated that federal wildland fire management agencies use a single decision support process that would "provide situational assessment, analyze hazards and risk, define implementation actions, and document decisions and rationale for those decisions" (USDI, USDA 2009 pg. 7).

Current policy requires that federal firefighting agencies publish WFDSS decisions for fires that escape initial attack, exceed initial response, or are being managed for both protection of values-at-risk and resource benefit objectives (NIFC 2017). However, some internal reviews have questioned whether fire managers are using WFDSS to its full potential (USDI 2017, WFMRDA 2015). For instance, the Wildland Fire Management Research, Development and Application Program (RDA) who oversees the development and use of WFDSS produced a 2014 review of published incident decisions which stated that "most incident objectives are written generally enough that they could apply to any fire in the country" (WFMRDA 2015 pg. 1). Their review concluded that the existing level of use by managers make it difficult to prioritize objectives and communicate the rationale behind incident decisions (WFMRDA 2015). A U.S Department of Interior report following the Chimney Tops 2 fire in 2016 indicated that "Decision support tools appeared to play a limited role in supporting the risk management decisions" and cited "technical and cultural barriers" to the use of WFDSS in informing and documenting decision making during the incident (USDI 2017 pg. 106). Despite these internal findings, very few systematic research efforts have explored fire manager use of WFDSS for risk-informed decision making.

This research presented here addresses the lack of research on WFDSS adoption by exploring perceptions of satisfaction, benefit and use among WFDSS users in the Pacific Northwest, USA. We also explore managers' perspectives about existing or future training and support surrounding WFDSS. We conducted interviews with a stratified sample of 42 WFDSS users with different WFDSS user roles and responsibilities in an attempt to better understand to what extent WFDSS supports the risk-informed decision-making needs of fire managers. Results of this study could help inform future FMDSS development by better targeting FMDSS development efforts towards the needs and concerns that fire managers have involving the use of FMDSS in fire management decision making. Additionally, this study could help improve future FMDSS implementation efforts by providing insight into the factors that contribute to FMDSS adoption success.

2: Literature Review

Wildland Fire Science and Technology Transfer through Decision Support Systems

Federal wildland fire policy mandates the use of "best available science" in wildland fire management and decision making (USDI, USDA 2009, WFEC 2014). The USFS 2012 Planning Rule and the USFS Land Management Planning Handbook provide limited clarification defining best available science as that which is "accurate, reliable, and relevant" and "currently available in a form useful… without further data collection, modification or validation" (USDA 2012 pg. 21261, USDA 2013 pg. 5). However, the abundance of existing scientific information, along with the contradictory results and uncertainties inherent in research findings contribute to considerable ambiguity and present difficulties for fire managers who must attempt to obtain and evaluate what constitutes best available science while making complex decisions within highly compressed time frames (Wright 2010). Existing research indicates that new science findings are often most useful when they are delivered to fire professionals in the form of a tool that addresses a specific management issue, such as a fire behavior model or spatial dataset (Barbour 2007).

A decision support system (DSS) aggregates scientific findings such as datasets and models into an interactive tool that supports management decision making (Mann and Watson 1984). Existing literature describes numerous fire management decision support systems (FMDSS) that synthesize wildland fire science results such as spatial data, fire behavior modeling programs and risk analysis frameworks into interactive decision support applications addressing various aspects of fire management decision making (e.g. fuel management, strategic and tactical fire suppression resource management, initial attack response, large fire management) (O'Conner 2016, Martell 2015, Mavsar et al. 2013, Minas et al. 2012, Pacheco et al. 2015, Sakellariou et al. 2017).WFDSS is an example of widely used FMDSS among federal agencies in the United States. WFDSS is a web-based application that synthesizes geospatial data, fire behavior model outputs, risk analysis frameworks, and cost evaluation tools. It is intended to help fire managers such as Line Officers (e.g. Forest Supervisors and District Rangers), natural resource specialists, and fire specialists to develop strategic fire management direction and communicate that direction to the Incident Commander (IC) or Incident Management Team (IMT). The direction given in a WFDSS decision outlines the strategic fire management approach (e.g. suppression, contain / confine, point protection, monitor) that best mitigates risk and achieves land management objectives (e.g. allowing fire to burn where beneficial, protecting values such as residences, infrastructure, threatened / endangered species habitat, cultural resources) given existing constraints (e.g. expected weather / fire behavior, availability of firefighting resources) (Noonan-Wright et al. 2011, USGS 2019).

Line Officers are USFS employees whose supervisory line of command runs directly back to the Chief of the Forest Service (USDA 2005). Among other duties, Line Officers have the responsibility for overseeing fire management and the authority for fire management decision making. They often rely heavily on the input and advice of their subordinate staff, including natural resource specialists (e.g. foresters, wildlife biologists, hydrologists, botanists, archaeologists, recreation managers etc.) and fire specialists (e.g. fire management officers, fuel / prescribed fire specialists, fire planners etc.) to assist them with fire management decision making (WFMRDA 2018).

Line Officers delegate authority to carry out the strategic direction in WFDSS to the Incident Commander (IC), who has responsibility for selecting firefighting strategies and tactics in order to implement that direction. ICs and their subordinates fill the various Incident Command System (ICS) functions of command, operations, planning, logistics, and finance/administration—they are collectively referred to as the Incident Management Team (IMT). The IC and/or the IMT for a given fire event may be ad-hoc depending on the scale and complexity of an incident,, with members drawn from local fire and resource specialists, or may be a national team with standing rosters of highly qualified and experienced personnel who are capable of managing the largest and most complex of wildfire incidents.

A typical WFDSS decision consists of a multi-page long PDF document with maps, figures, tables, and supporting text that at a minimum must contain: 1) a planning area; 2) a relative risk assessment; 3) an organization assessment; 4) a decision approver; 5) a strategic objective; 6) an action item; 7) an estimated final cost; 8) a decision rationale. See Figure 1.1 for a visual representation of the mandatory components of a WFDSS decision as well as the ideal WFDSS decision development and implementation workflow.

The planning area is the geographical representation of the area being considered in the decision. When the planning area is set, WFDSS auto-populates the decision document with the strategic objectives found within the planning area, as well as the known values within the planning area. As such, the planning area defines what existing strategic fire management or land management objectives are considered in the decision document, as well as what known values are reflected in subsequent risk assessments. A relative risk assessment provides a qualitative visualization of the importance of various values on the landscape, the probability that fire will impact those values, and the magnitude of potential risk the fire poses to those values. The organization assessment combines the relative risk assessment with considerations of implementation difficulty (e.g. fire duration, firefighter exposure, availability of resources) and socio-political influences (e.g. jurisdictions involved, extent of agreement among cooperators, media interest) to produce a recommended incident

management level as well as a supporting bar chart that helps inform what level of incident management is needed. The decision approver implicates individuals (e.g. Line Officers and their representatives) who have the authority to approve the final WFDSS decision. WFDSS decisions must contain at least one strategic objective (e.g. suppress fire at smallest size, manage fire for resource benefit), and more often contain multiple strategic objectives. Strategic objectives express overarching guidance for fire management based on the direction found in existing fire management or land and resource management plans. Decisions also require at least one action item that describes how the strategic objectives will be achieved, for instance, if a fire had a strategic objective of "Allow fire to play a natural role in Wilderness Areas as nearly as possible," an action item might be "Use existing trail systems, vegetation changes and natural barriers where feasible to keep fire within the Wilderness Area." The aggregation of action items in WFDSS is referred to as the course of action, and describes how the fire will be managed to meet objectives while mitigating risk. The estimated final cost enumerates the expected cost of implementing the course of action. Finally, a WFDSS decision must include a decision rationale drafted by the Line Officer that articulates why the previously described course of action was selected (USGS 2019).

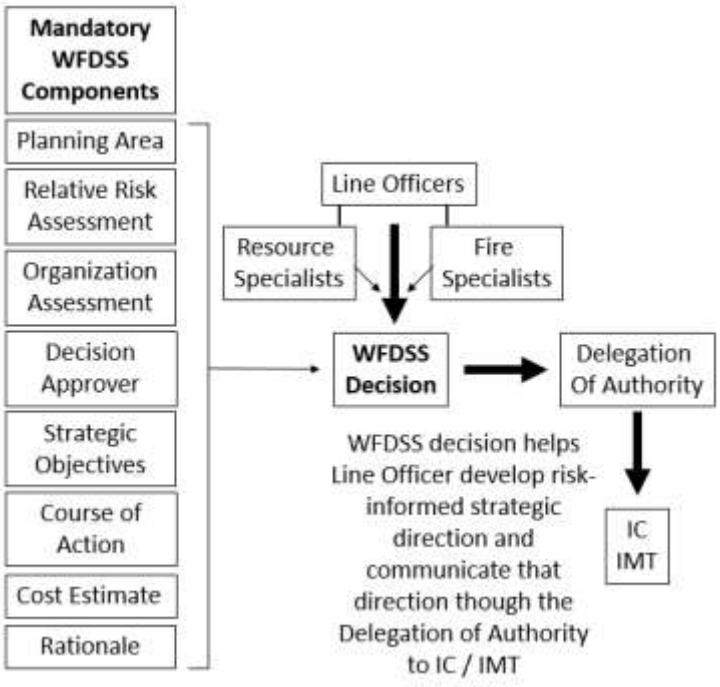

Figure 1.1. Intended WFDSS decision-making process
Line Officers (assisted and advised by their resource and fire staff) bear responsibility for developing a WFDSS decision that at a minimum includes the mandatory components listed. The strategic management direction developed in WFDSS is reflected in the Delegation of Authority letter and is implemented by the Incident Commander (IC) / Incident Management Team (IMT).

WFDSS is based on the principles of risk-informed decision making, which helps managers develop decisions that consider the probability of beneficial and detrimental fire impacts to values on the landscape (e.g. residences, infrastructure, land management objectives, air and water quality) in order to provide broad strategic fire management direction (Noonan-Wright et al. 2011). Risk-informed decision making involves analysis and deliberation that follows a cycle of: (1) establishing situational awareness; (2) analyzing risk; (3) controlling risk; (4) making a decision; (5) implementing the decision; and (6) evaluating the decision (Taber et al. 2013). Figure 1.2 provides a visual representation of this process, and shows how some WFDSS elements support the various stages of risk-informed decision making. WFDSS helps fire managers gain situational awareness by aggregating basic information (e.g. fire name, size, cause, jurisdiction), spatial data (e.g. fire perimeter, fire behavior model outputs, location of values at risk), and management objectives (e.g. strategic objectives pre-identified in existing management plans, or those developed specifically for the incident). Risk assessment tools in WFDSS (e.g. (relative risk assessment, rapid assessment of values at risk) help decision makers analyze risk by identifying the values at risk, the extent of the fire related hazard, and the probability of the fire hazard impacting values. It assists fire managers with risk control through cost estimators and a systematic process for describing how managers will meet objectives while mitigating identified risks and managing financial costs. Fire managers can use outputs from WFDSS (e.g. course of action, rationale document) to support decision implementation by including these outputs in the Delegation of Authority, the legal document that provides direction to Incident Commanders (IC) and Incident Management Teams (IMT). WFDSS decisions are archived, making WFDSS the official database of record for fire management decision making. Finally, WFDSS prompts fire managers to consider periodic assessments of decisions in order to facilitate decision evaluation (Taber et al. 2013).

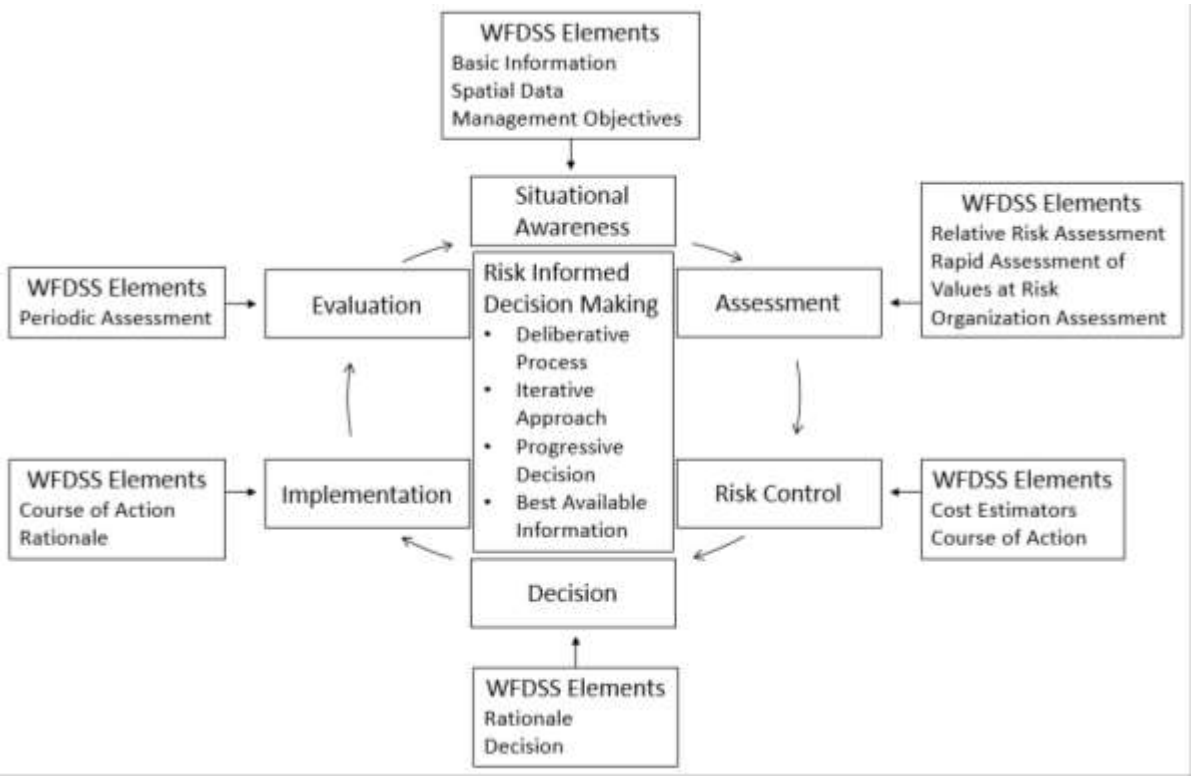

Figure 1.2. WFDSS and risk-informed decision making, adapted from Taber et al. 2013
Risk-informed decision making follows a cycle of: (1) establishing situational awareness; (2) analyzing risk; (3) controlling risk; (4) making a decision; (5) implementing the decision; and (6) evaluating the decision. Various elements within WFDSS support the different stages of the risk-informed decision-making cycle.

Despite the proliferation of FMDSSs such as WFDSS, researchers have observed that their use by fire managers has been limited. Some perceive a growing disconnect between the FMDSSs currently available and the decision support needs of fire managers, although it is not clear what specific needs are not being met (Martell 2011, Pacheco 2015). The bulk of existing FMDSS literature introduces new FMDSSs, presents underlying theoretical approaches used by various models, or discusses challenges associated with accurately representing the many conflicting objectives, complexities, and uncertainties that surround fire management decision making (Kalabokidis et al. 2002, Martell 2015, Mavsar et al. 2013, Miller and Ager 2013, Minas et al. 2012, Rachaniotis and Pappis 2006, Sakellariou et al. 2017, Thompson and Calkin 2011, Thompson et al. 2017). While much of the FMDSS literature asserts that improved decision-making outcomes either have resulted or will result from using FMDSS, very little existing work focuses on the substantiation or evaluation of these claims as a primary study objective. Consequently, there is considerable opportunity to apply results from DSS implementation literature developed in other disciplines including decision sciences and business toward the evaluation of FMDSSs (Pacheco 2015).

Accordingly, we next review salient lessons from existing science on DSS development, adoption and evaluation.

Evaluating DSS Success

Evaluating DSS adoption presents a challenge because the benefits of improved decisions stemming from DSS use are often intangible and difficult to measure directly (Barki and Huff 1990, Bokari 2005, Galletta and Lederer 1989). Existing DSS implementation research widely accepts qualitative or quantitative metrics for system usage, user satisfaction, and perceived benefits as indicators of success because those metrics are believed to indicate that the application fulfills the decision-making needs of users (Barki and Huff 1990, Bokari 2005, Fuerst and Cheney 1982, Guimaraes et al. 1992, Ives et al. 1980, Lucas 1987). System usage often is considered the least reliable metric of success when DSS use is mandatory, as is the case with WFDSS. This is because decision makers may be required to use the DSS despite experiencing no benefit to their decision making (Bokkari 2005).

Existing theory surrounding DSS development and use suggest three primary factors that contribute to DSS success: (1) DSS user characteristics; (2) characteristics of the DSS; and (3) the implementation process by which the DSS was introduced to potential users. These three factors are important for success primarily because they shape user sense of satisfaction and perceived benefits towards a DSS (Barki and Huff 1990, Fuerst and Cheney 1982, Guimaraes et al. 1992). Considering or evaluating the above characteristics can help explain users' satisfaction or perceived benefits for a DSS or help determine the success of the application (Barki and Huff 1990, Bailey and Pearson 1983, Ives et al. 1983, Mahmood and Sniezek 1989, Zviran and Erlich 2003).

DSS theory places user characteristics that influence perceptions of DSS benefit and satisfaction into three primary categories: (1) cognitive style; (2) personality, and (3) demographic variables (Zmud 1979, Alavi and Joachimsthaler 1992). Cognitive style refers to the diverse ways that individuals process information, solve problems, and make decisions (Goldstein and Blackman 1978, Huysman 1970). In existing DSS research, cognitive style often pertains to whether the user employs an analytical or heuristic decision-making approach (Barki and Huff 1990, Green and Hughes 1986). Analytical decision makers prefer quantitative data, linear step-by-step processes, and models. Heuristic decision makers rely on experience, intuition and trial-and-error (Alavi and Joachimsthaler 1992). Select research suggests greater DSS adoption among analytical decision makers (Davis and Olson 1985, Lu et al. 2001, Mysiak et al. 2003, Zmud 1979), although inherent difficulties with defining and measuring cognitive style have led to varying interpretations of this result (Alavi and

Joachimsthaler 1992, Doktor and Hamilton 1973, Fuerst and Cheney 1982, Green and Hughes 1986, Lu et al. 2001, Mysiak et al. 2003, Zmud 1979).

Personality traits are frequently described as characteristics that help an individual adjust to the people, events and situations that they encounter (Alavi and Joahimsthaler 1992, Zmud 1979). Personality traits can influence user beliefs and attitudes towards a DSS, which can in turn influence their satisfaction with a DSS (Alavi and Joachimsthaler 1992, Barki and Huff 1990, Davis et al. 1989, Liang 1986, Lucas 1978, Zmud 1979). For instance, some existing research indicates that individuals who exhibit high degrees of extroversion and willingness to change are more likely to perceive benefit in using a DSS and consequently contribute to adoption success. On the other hand, individuals who are more willing to accept risk or who assert their opinions as fact regardless of other evidence or perspectives (i.e. dogmatic) are less likely to perceive benefits resulting from DSS use, which will lower application success (Alavi and Joachimstaler 1992, Barki and Huff 1990, Zmud 1979). However, relatively few research studies have focused explicitly on the relationship between personality traits and DSS success, and some argue that personality characteristics likely have only a small effect on DSS success. (Alavi and Joachimsthaler 1992). Demographic factors such as age, gender, and education may also influence DSS adoption because they can influence user willingness to use or interest in learning new applications such as DSSs (Alavi and Joachimstaler 1992, Lucas 1978, Fuerst and Cheney 1982, Zmud 1979). For instance, select research indicates that DSS success improves among younger and more educated users (Fuerst and Cheney 1982, Lucas 1978, Zinkhan et al. 1987). However, insufficient research examining demographic factors prevents drawing strong conclusions about their role in DSS success (Alavi and Joachimstaler 1992).

Existing findings from DSS implementation research indicate that the characteristics of the DSS also contribute to its success, including the data, models, analytical tools, processes and user interface of the DSS. The quality and usefulness of outputs associated with a DSS are another frequently mentioned characteristic influencing adoption success (Fuerst and Cheney 1982, Lucas 1975). A poorly designed DSS user interface may negatively impact user satisfaction and perceived benefits by decreasing user's ability to use the program or obtain information that improves decision making (Barki and Huff 1990, Lucas 1978).

User satisfaction and perceived benefits are believed to increase when users perceive DSS outputs as accurate and relevant to the problem being considered. Additionally, user satisfaction and perceived benefits are thought to increase when the design of the user interface contributes to ease of use and the when outputs are delivered in a timely manner (Bailey and Pearson 1983, Barkhi and Huff 1990, Dulcic et al. 2012, Fuerst and Cheney 1982, Guimaraes et al. 1992, Loucks 1995, Mysiak et al. 2005). Finally, DSS research indicates that user satisfaction and perceived benefit increase when

users observe positive changes to decision making resulting from the outputs of the DSS (Bailey and Pearson 1983). Some FMDSS research speaks to the importance of DSS characteristics by warning against developing FMDSS that are excessively complex or require too much time for fire managers to use effectively (Pacheco 2015, Thompson and Calkin 2011). However, there are few efforts to actually assess these outcomes among populations of end users for FMDSS programs.

Finally, lessons from existing DSS research indicate that the form or structure of implementation processes introducing DSSs to potential users are an important factor influencing user satisfaction and perceived benefit associated with DSS success. Many researchers conclude that actively involving users in the DSS development, support from high-level management, and user training are critical to successful implementation (Barkhi and Huff 1990, Fuerst and Cheney 1982, Guimares et al. 1992, Loucks 1995). Alavi and Joachimstaler (1992) suggest that user involvement and user training are more influential to the success of a DSS than users' cognitive or personality characteristics. User involvement in the initial or ongoing development of a DSS can foster a sense of ownership that increases potential use, superseding personality traits associated with preconceptions. Direct involvement in DSS development or improvement can increase user satisfaction with the DSS and the importance a decision maker associates with the application (King and Rodriquez 1981, Zinkhan et al. 1987). Similarly, user training can help explain why the DSS is important or necessary and demonstrate how it can be used to improve decision making. Such opportunities can alleviate pre-existing user notions about the DSS and increase perceptions of satisfaction and benefit (Alavi and Joachimstaler 1992). Loucks (1995) considered training more important than the "user-friendliness" of a DSS, pointing out that as DSSs evolve and become easier to use, they often also increase in complexity which requires that users have additional training in order to develop proficiency with the DSS. Lack of training significantly contributes to user dissatisfaction (Guimares et al. 1992, Fuerst and Cheney 1982, Sanders and Courtney 1985). Finally, high-level management support can promote favorable attitudes towards the use of a DSS, as subordinates are likely to follow the lead of supervisors and senior managers who actively use a DSS (Lucas 1978, Sanders and Courtney 1985).

The few published efforts discussing FMDSS success corroborate existing lessons from broader DSS literature and introduce other considerations. Martell (2011) reflected on his long-term experience with FMDSSs to conclude that fire manager adoption of FMDSS increases when: 1) FMDSS researchers examine issues that fire managers indicate are important decision-making needs; 2) FMDSS researchers work closely with fire managers and technical specialists throughout the development of the FMDSS; 3) FMDSS researchers have practical experience in fire management as well as DSS development, and 4) FMDSS researchers train interested individuals to work for the organization utilizing the FMDSS and who can continue to invest in its implementation. Similarly,

Pacheco et al. (2015) cited insufficient fire manager involvement in the design and implementation of a FMDSS as one reason for the lack of FMDSS adoption. Technological improvements to data acquisition or analysis should only compliment—and never replace—the value of experience and intuition or the role of a fire manager as the ultimate decision maker (Mavsar et al. 2013, Martell 1982, Pacheco 2015).

In summary, existing literature provides a strong consensus for the need to evaluate DSS adoption, and demonstrates that considerable thought has been given to the problem of how to evaluate DSSs. Much of the literature surrounding DSS adoption centers on measures of perceived user satisfaction and benefit. Within the field of wildland fire management, a concerted effort has been made to develop FMDSS for the purpose of improving various aspects of fire management decision making. However, despite concerns that FMDSS adoption is lacking, no scientific effort has been made towards evaluating FMDSS adoption by fire managers. This research begins to address the large gap that exists in current understanding of FMDSS adoption success. Specifically, it applies findings from DSS implementation literature to the field of FMDSS. DSS implementation literature holds that DSS adoption success is influenced by some characteristics that describe DSS users as well as several characteristics that describe DSS design and function. Existing research presents varying results as to the relative importance of these characteristics to DSS adoption success. However, DSS implementation literature consistently finds that elements of the implementation process surrounding a DSS strongly influences DSS adoption success. Furthermore, the abundance and consistency of research regarding the importance of training for DSS indicates that this implementation characteristic is among the most critical to DSS adoption success. This study examines the Wildland Fire Decision Support System as an example of an FMDSS facilitating wildland fire science and technology transfer. We use existing theory surrounding DSS adoption success to explore factors that have contributed to or hindered WFDSS adoption. Accordingly, the following research questions guide our effort:

1) What benefits do fire managers attribute to WFDSS?
2) How satisfied are users with the WFDSS application?
3) What makes effective training for WFDSS?

3: Methods and Analysis

Methods

We used an inductive, qualitative approach to explore perceptions of satisfaction and benefit and training for WFDSS among a sample of users. Inductive research allows findings to emerge from the data during the course of the inquiry and does not involve testing of pre-defined deductive hypothesis. We selected an inductive approach because it is best suited for exploratory research characterized by a lack of past findings, in our case the lack of previous studies focusing on FMDSS adoption success (Strauss and Corbin 1990). A qualitative approach also is appropriate for this effort because our intent was to allow users the opportunity to describe in-depth their perceptions surrounding WFDSS, and because a qualitative approach allows new information to emerge through exploration of novel themes arising from our data (Bryman 2012, Thomas 2006).

We defined our sample population as USFS WFDSS users in the Northwest Geographic Area (NWCC), as well as USFS employees who took the 2017 S-495 Geospatial Fire Analysis class. We chose the USFS because it is the largest and most influential of the federal agencies that are mandated to use WFDSS in wildland fire management, and thus offered the largest population of WFDSS users from which to select interviewees. Selecting a single federal agency for this exploratory research also allowed us to control for potential differences in WFDSS use and training associated with variability in policy across agencies. Likewise, we chose to focus on a specific region because support and administrative functions for WFDSS are often conducted at the Geographic Area (GA) level following the delineations defined by the National Interagency Coordination Center (NICC). Selecting one area for our sample frame provides a logical starting point for exploring end user perspectives operating within existing agency dynamics. We selected the NWCC for study because it has a long history of large fire management requiring complex decision making and because RDA staff indicated that fire managers in this region were likely to be relatively familiar with WFDSS. Furthermore, the NWCC is similar to other western GAs in that it has a continuous, approximately three-month-long fire season during the summer and a highly structured federal fire management organization. These factors make the NWCC an ideal location from which to obtain substantial information that may be relevant to other places in the US. S-495 Geospatial Fire Analysis is an advanced class that teaches students how to use the fire behavior models within WFDSS. We included these students in order to capture the views of WFDSS users who had attended an advanced formal training concerning WFDSS.

We employed a stratified random sampling approach of WFDSS users to ensure representation of various perspectives that may be associated with the FMDSS. More specifically, we segmented WFDSS users in the NWCC by the various roles assigned to them which define their functions and privileges within the system. We randomly sampled within each strata in order to collect data from a wide cross section of WFDSS users with varying experiences with the program. The sampling process began by obtaining a list of USFS WFDSS from the RDA. We then separated these potential study participants into groups based on their WFDSS user role. The user was assigned the role with the highest level of permissions granted in instances where a user had multiple roles. The five resulting groups (or "strata") were: dispatcher, viewer, author/data manager, fire behavior specialist and Geographic Area editor. We added an additional strata consisting of USFS employees who had attended the 2017 S-495 Geospatial Fire Analysis class. We used the Microsoft Excel RAND function to randomly assign every user within each strata a unique identifier number, and then sorted these identifiers from lowest to highest. We contacted potential interviewees in each strata by starting with the lowest identifier number and progressing sequentially higher. This approach of selecting interviewees ensured a random sample within and across each strata.

We contacted all potential study participants multiple times via email and phone in order to maximize participation. We sent emails inviting potential interviewees to participate and then called those who did not respond to the email within 7-10 days. We repeated the cycle of emails and phone calls after another 7-10 day period of non-response before removing individuals who did not respond from consideration. We continued to contact potential interviewees and conduct interviews until theoretical saturation—the point at which we heard the same answers from interviewees from each of the strata and no new information was forthcoming (Morse 1995). Researchers contacted 106 WFDSS users at least once for this research, and interviewed 42. Interviews lasted between 10 and 80 minutes, with an average of 45 minutes. All interviews were audio recorded, and subsequently transcribed word-for-word for the coding described below.

We created a semi-structured interview protocol designed to help guide interviews. A semi-structured interview protocol is a series of open-ended questions intended to prompt a dialogue between the interviewee and the interviewer. Semi-structured approaches to interviewing allow researchers the flexibility to ask additional questions to further explore initial responses implicated by the interviewee (Bryman 2012). Questions covered in the protocol were designed to reflect the range of factors that existing literature indicates are potential influences on DSS success. The protocol included questions that asked about the interviewee's experience and confidence with using WFDSS, how they use WFDSS as a part of their job, the components of WFDSS they found useful, the utility of WFDSS in fire decision making, and their suggestions for how WFDSS could be changed to better

meet their needs. Subsequent questions were intended to better understand the perceptions of satisfaction and benefit that WFDSS users have towards the program or describe the characteristics of WFDSS that contribute to those perceptions. Additionally, our protocol included questions exploring how respondents learned to use WFDSS, existing training opportunities and support networks, and suggestions for improving future training. Finally, our interview protocol concluded with questions about respondents day-to-day job duties, their federal paygrade level, and their background and qualifications in fire management. We included these questions to better understand the characteristics of WFDSS users that might influence adoption success.

Analysis

Our data analysis followed qualitative data analysis processes of analytic induction and thematic analysis. Analytic induction is an approach for systematically evaluating similarities and differences in participant responses in order to develop themes and relationships between concepts emerging from within the data (Gomm 2009, Ryan and Bernard 2000, Aronson 1994 Boyatzis 1998). Thematic analysis uses a coding process to discover patterns within data in order to develop emerging themes (Aronson 1994 Boyatzis 1998). Our data analysis involved three rounds of successively restricting transcript coding using the NVivo software for qualitative data analysis. Transcribed interviews were first coded to generate a comprehensive list of topics discussed during the interview process, what often is called topic coding in existing methodological literature. A second round of "descriptive coding" focused on summarizing patterns in interviewee response for each topic or drawing connections among them (Richards 2014). Finally, a third round of what is frequently called "analytic coding" documented patterns within descriptive themes to articulate overarching connections between respondents' experience with WFDSS or associated trainings and to explore the reasons behind those outcomes (Ryan and Bernard 2000). Each round of coding entailed a separate reading and documentation of all data collected in the research. Two researchers coded a portion of the data separately at each stage of the process and compared their initial findings in an effort to establish intercoder reliability (Bryman 2012). They addressed any inconsistencies in their findings and modified the definitions or procedures used in the coding process to ensure that replication of the coding process by other researchers would find similar conclusions. Lastly, both researchers examined the transcripts and identified quotations that best represented the final themes.

4: Results

Primary Perspectives Surrounding WFDSS Utility

Interviewees indicated that they appreciated the overall intent of WFDSS as a decision support tool that facilitates risk-informed decision making and establishes an official database of record for documenting fire management decisions. However, they noted that numerous challenges complicate the use of WFDSS and frequently prevent managers from fully realizing its intended purpose. Interviewees indicated that they used WFDSS primarily to document decisions and justify actions already taken rather than as an analytical or deliberative tool that informed their decision making. Similarly, participants described how they usually had a predetermined idea of what fire management decision needed to be made, and that going through the decision development process in WFDSS usually did not significantly change their predetermined idea. They described developing fire management decisions primarily through conversations with other managers. As one interviewee described:

> I guess my opinion, it seems like we use the system more for documenting the decision that we know we want to make already, [rather than] utilizing the system to truly inform a decision… we use it to just basically document the decision we've already come to.

We describe the primary influences on the use of WFDSS as a documentation tool in the section titled "Challenges to WFDSS use."

Interviewees described that on-the-ground actions are sometimes inconsistent with the decisions documented in WFDSS. These disconnects make it difficult for WFDSS users to realize its intended purpose of facilitating analysis and deliberation that results in a risk-informed decision providing direction to the Incident Commander (IC) or Incident Management Team (IMT). Interviewees explained that the direction given in WFDSS is not always carried out, and described several ways this disconnect or conflict could occur. Sometimes disconnects occur because of a communication breakdown, for instance when the Line Officer does not communicate the WFDSS decision to the IMT through the Delegation of Authority letter or elsewhere in the briefing packet. Other times the IMT disregards the direction given them from the WFDSS decision. Changes in the fire situation (e.g. wind shift, fire behavior) or political pressures also contributed to actions that are inconsistent with the direction given in WFDSS. Participants indicated that experiencing disconnects between WFDSS decisions and on-the-ground actions decreases their perceived utility for the program. As one fire manager described:

> My concern often is that there's typically a significant disconnect between the delegation of authority and the decisions that are documented in WFDSS. We've struggled vitally to try to bring those together better… We can have some long duration incidents…having [the WFDSS decision] tied to not only the delegation, but what we're actually doing, and then getting the teams to connect with that as well, it's been a real struggle.

Despite inconsistencies between documentation and actions, interviewees expressed an overall appreciation for the role that WFDSS plays in documenting, validating, and justifying fire management decisions. That appreciation stemmed from the fact that WFDSS allows mangers to tell a more complete story of why they made the decisions they did based on information that they had at the time. Participants explained that fire management decisions are often scrutinized in hindsight, and that using WFDSS to document the logic associated with particular decisions provides an official database of record that helps them justify or articulate their decision making. Participants indicated that they also used WFDSS as a validation tool to fact check their decision and to make sure that they had considered the full breadth of values at risk or land management priorities present in the fire situation. One interviewee described the usefulness of WFDSS as such:

> But, as you go through that process, as you go through there, it's validation that you haven't missed something. There is a lot of utility in that I think. Just going through the process to be sure you don't miss something. There are occasions where you're like, 'oh yeah, I didn't think about that.' There's a value at risk I didn't think of or there's a management area that I didn't know about. That can certainly alter your strategy and your approach… but I think generally, we kind of know what we're gonna do. WFDSS has been a place to validate that and document it.

Interviewees described finding value in the process of interaction and deliberation facilitated by WFDSS. They felt that WFDSS provides a consistent setting or framework that facilitates the collaborative reasoning and decision making among a range of land management and firefighting professionals. For example, participants described WFDSS as especially beneficial when facing complex decision making on multi-jurisdictional fires with numerous stakeholders. They recounted fires during which Line Officers, fire managers, and natural resource specialists gathered in one room, projected WFDSS onto a screen, and worked through the decision development process in a collaborative manner in order to come to an effective management strategy that everyone could agree to. One participant described that using WFDSS as a decision-making framework enhances the ability

for stakeholders outside the Forest Service, such as state land or fire management agencies, local law enforcement and fire departments, and elected officials to provide their input. As one respondent summarized:

> You know, overall, I find the usefulness of WFDSS to be in guiding a conversation, is how I like to see it. We're guiding a conversation with the right people in the room to move through it. The value's more in the process or the journey than clicking these boxes and trying to get it done as quick as you can, type of thing.

Interviewees described the aggregation of data within WFDSS as a particularly valuable element supporting fire management decision making. They felt that the opportunity to display relevant information though WFDSS in a geographical or spatial context helps enhance situational awareness of the factors that influence risk-informed decision making. Particularly important information described by participants includes the location of the fire, values at risk such as residences or infrastructure, land management priorities (e.g. threatened or endangered species habitat), objectives from land or fire management plans, management action points that trigger predetermined actions (e.g. evacuations, firing operations), and fire behavior model outputs indicating where the fire may spread. Gathering relevant data into a single application and displaying it spatially allows managers to rapidly access and process information for developing objectives and determining a strategy for managing a fire. As one interviewee put it:

> Well, I think part of it that is useful is, it does walk you through it step-by-step as far as describing, the piece of ground as far as values at risk. It walks you through taking a look at the big picture, here's the fire, here's what's around it, here's the current weather conditions and all these factors that paint the bigger picture of that incident. I think it does a good job with that, just give the overall view of things.

Challenges to WFDSS Use

Interviewees indicated that several inter-related factors including lack of time, the complexity of the WFDSS program, lack of proficient WFDSS users, and the high experience level of fire managers challenge the use of WFDSS as it is intended. These factors contribute to managers using WFDSS primarily for documentation rather than for facilitating risk-informed decision making and to disconnects between WFDSS and on-the-ground actions.

Interviewees described lack of time as a primary reason for WFDSS becoming a documentation exercise and for disconnects between WFDSS decisions and on-the-ground actions. They explained that the operational tempo of fire frequently exceeds the capacity of managers to produce a WFDSS decision. In these cases, the time required to prepare a quality WFDSS decision that is supported by thoughtful analysis is often better spent developing a strategy through dialogue with the IC or IMT and verbally communicating intent. Interviewees indicated that direct dialogue with the IC or IMT is particularly important during rapidly developing urban interface fires or fires transitioning from local incident management to national Type 1 or 2 incident management. Frequently, more pressing concerns such as coordinating evacuations or preparing to in-brief an IMT take precedence over completing WFDSS. In the aforementioned situations, WFDSS decisions are completed after the fact, and largely serve to document the actions that have already occurred.

Interviewees also cited the timeframe required to develop a WFDSS decision as a contributing factor to conflict between management actions and the WFDSS decision. Higher priorities sometimes prevent WFDSS decisions from being completed in time to be added to the Delegation of Authority letter and IMT briefing packet, which sometimes leads to inconsistencies between the direction given to an incoming IMT and that direction documented later in WFDSS. Similarly, participants explained that the time it takes to update a WFDSS decision frequently contributes to inconsistencies between WFDSS direction and on-the-ground actions. Rapid changes in situational factors such as weather conditions or fire behavior influence rapid shifts in strategy that may differ from those originally documented in WFDSS. One interviewee described it this way:

> It's just a limitation of the program itself, I hope it doesn't come across as a criticism. But these incidents are often so rapidly evolving, and by the time you may complete a WFDSS, a half a burning or a full burning period has taken place and conditions have evolved. That's a reality.

Interviewees indicated that the complexity of WFDSS is a major challenge that limits the availability of skilled WFDSS users and contributes to the significant amount of time needed to produce a decision, which results in manager use of WFDSS primarily for documentation. Several interviewees compared their experiences using WFDSS to that of using GIS software in that the program requires a high level of skill and that it is constantly evolving. The high level of skill needed to run WFDSS increases the difficulty of using the system and requires the availability of proficient Authors in order to develop decisions in a timely manner. The Author user role is largely responsible for navigating the program, facilitating discussion, and drafting much of the WFDSS decision

content. Participants also indicated that WFDSS proficiency is a highly perishable skillset, and that most users do not spend enough time with the program to develop familiarity with its many components. Proficiency with WFDSS often is related to how frequently an individual uses WFDSS as a part of their daily job, or the level of fire activity experienced by a home unit. Units with more fire activity are more likely to have individuals who are proficient with WFDSS due to its frequent use, while units with less fire activity use the program less frequently, and thus might lack individuals with strong WFDSS skills. Few interviewees believed that they used WFDSS regularly enough to develop true expertise with the program. As one experienced WFDSS user explained:

> The decision side of WFDSS is what is clunky and not intuitive, and very frustrating. Because it's not intuitive and complex, and because people aren't always in there, you know, they don't have that proficiency in there every single week or every single month, it's difficult for people. So it's frustrating to them. What happens is it takes so long to get a good WFDSS out that it's failing in its progress. It just becomes a documentation tool.

One of the primary challenges of using WFDSS as described by participants concerned bringing the right people together at the right time to produce a WFDSS decision in a timely manner. Interviewees described conflicting job duty priorities and a lack of interest from non-fire program areas as barriers to developing and maintaining a cadre of experienced WFDSS Authors. Many "WFDSS experts" are fire staff who usually have operational responsibilities that prevent them from being able to coordinate the WFDSS effort. On the other hand, resource specialists often possess skillsets such as database management, GIS, and technical writing that make them good "WFDSS experts," but they are frequently unavailable to assist with WFDSS on weekends, after hours or because they have their own workload to accomplish. Other participants felt that completing WFDSS is generally seen as the responsibility of the fire organization, which contributes to decreased interest in WFDSS involvement from Line Officers and natural resource specialists.

Interviewees partially attributed the lack of broader Line Officer or resource specialist interest in WFDSS to its initial implementation process. This is because WFDSS was introduced only through the fire organization, which some respondents felt gave the impression that the input of natural resource specialists was not needed, and potentially discouraged them from participating in the decision-making process. As one fire manager summarized:

> …it just seems like it the way that [WFDSS] rolled out was that it was a requirement that fire had to do…I think it's evolving, and it has evolved over the last, you know, five years, as

> we've had more fires and Line Officers have, like, had to learn on the fly. I think they take more ownership of it now, but there's still people within their shops, within their staff, that I don't think are on board or understand how much it impacts them.

Interviewees cited political pressures as another contributing factor to the lack of consistency between decisions documented in WFDSS and actions taken on-the-ground. They indicated that concern from the public and elected officials can sway fire managers towards a course of action that is different than the one articulated in the WFDSS decision. As one participant summarized: “There's way more political considerations that are not necessarily encompassed within WFDSS that affect those decisions rather than the documentation and WFDSS.”

Finally, participants indicated that experience can influence both the incongruence between actions on-the-ground and the WFDSS decision and managers use of WFDSS primarily for documentation. Some interviewees described how WFDSS may not yet be fully accepted fire managers with a strictly operational background. They indicated that many IMTs do not care about the direction provided in a WFDSS decision, preferring instead to develop direction based on their own internal evaluation of operational needs and concerns. Experienced fire managers also described relying on their intuition and previous experience to make timely decisions without the assistance of WFDSS. They indicated that their long-term experience had allowed them to learn how fire behaves under various fuel, weather or topographic scenarios and become familiar with how values at risk are impacted by fire. Participants explained that during emerging incidents fire mangers often default to their experience and rely on their instincts because there is insufficient time or personnel available to develop a WFDSS decision. In these cases, WFDSS was used primarily to document the decisions and actions that resulted from conversations among experienced fire managers. As one interviewee recounted:

> I guess, maybe to put it a different way, if you've got those folks around, good experience and know the place and know how a fire's going to behave, then they're going to get, through their instincts and their experience, they're going to get you most of the way where the WFDSS decision would take you.

The challenges described by participants above could limit the circumstances where WFDSS is perceived as beneficial or useful. For instance, participants described how WFDSS is likely to be more useful during small natural ignitions in remote wilderness areas. Higher likelihood of benefit might also occur between days of high fire growth on large fires, when important values are not

immediately threatened, when proficient WFDSS users are available to drive the program, and when there is sufficient time to assemble the necessary people and navigate the WFDSS process.

Existing Training and Training Preferences

Interviewees described WFDSS training opportunities as inconsistent. They associated that inconsistency in training to variability in the quality of WFDSS decisions produced and in WFDSS use across forests and ranger districts in the NWCC. Some interviewees recounted that initial WFDSS training in 2009 followed a "train the trainer approach," with in-person training offered to high level regional staff who were then expected to train others. Participants felt that this approach was not always successful because the newly trained individuals were not experienced enough or did not have enough technical skill with WFDSS to effectively teach others. Participants described that current WFDSS training opportunities usually consist of informal, annual "WFDSS refreshers" taught at the local level by individuals who are considered the most experienced WFDSS users. Interviewees indicated that training effectiveness and quality varies based on the skill level of the individuals facilitating the refresher. For example, a few participants felt that they received adequate training because a highly proficient WFDSS user developed extensive local training opportunities, while other participants described difficulties learning how to use WFDSS because a lack of local expertise prevented the development of high-quality trainings. As one interviewee put it:

> I have found [local trainings] useful, if there's a lead other than on the district. If it's someone who is a good teacher that has those skills to be, like a data analyst skill set, to where there aren't many questions they can't answer, to come in and really help facilitate and drive, then yes. I think it's very beneficial. But if it's left up to the individual district, where the teachers are the core members, then we're just going to our skill level and we're not really able to stretch that skill level.

Several interviewees felt that in the absence of quality training they were left to figure out how to use WFDSS on their own through "trial and error" and "frustration." Many participants expressed appreciation for the abundant online training resources and help guides published on the WFDSS website, and the WFDSS server dedicated to training. However, interviewees indicated that most WFDSS users do not have the motivation or time to sift through online training resources in order to train themselves or to find a particular piece of information. For example, a few self-described "fire geeks" explained that they took the time and energy to explore online training resources because they valued the datasets and models contained within WFDSS and appreciated the

underlying intent. On the other hand, many interviewees indicated that they are unlikely to learn how to use WFDSS on their own, regardless of the amount of self-help materials, because they view it as just one more task that competes against other priorities for their already limited time and attention. As one respondent said:

> If you're on a forest that doesn't have somebody who knows what they're doing, I don't know how you're supposed to get the training. Honestly, web-based training, figure it out for yourself, that just doesn't work for a lot of people.

Participants indicated that WFDSS is best learned by doing, and emphasized the role of mentorships during on-the-job training. Participants stated that informal or online trainings are useful for introducing the basics such as the underlying intent, overall layout, or "button pushing" within WFDSS. However, working through WFDSS decisions on live fires is necessary in order to learn the intricacies of the program. As one interviewee put it: "The formal training somewhat [prepared me to use WFDSS], but the on-the-job stuff, I think just getting in and doing it a few times, that's how I learned the best anyway."

Interviewees explained that shadowing more experienced WFDSS users during fires was essential because it taught them the how to use WFDSS during real world situations, including time pressures. Several participants described having higher confidence with WFDSS following opportunities to use it on the job. Meanwhile, another interviewee who had only been to a classroom training felt that her preparation was incomplete without real-world experience.

Participants indicated that they would like more high-level agency support for WFDSS and advanced training targeted to key users. They indicated that the staff of many National Forests do not have the opportunity (e.g. high fire activity, staff with WFDSS skills and interest) to develop and maintain a local source of WFDSS expertise. Several interviewees described receiving extremely beneficial in-person assistance from RDA members during times of high fire activity. They used these experiences in their calls for additional and more readily available high-level support during times when the WFDSS skill level exceeds the ability of local resources. As one interviewee said:

> I think one of the big things I would change is I would lean hard towards having more of a national level support network for [WFDSS], folks like that [RDA member] level of skill… Calling somebody has always been great, but having them actually sitting here in person has been invaluable to us.

Interviewees described a need for additional, advanced WFDSS trainings to increase the skill level of active WFDSS users and thus improve local training efforts. Many participants indicated that they benefited the most from in-person training or on-the-job mentorship opportunities, although they recognized the associated increases in cost and time that such training entails. Several interviewees recalled individuals who had completed details, or short term work assignments with the RDA, and who had then returned to their home units with strong WFDSS skills and an enhanced ability to help others with the program. Interviewee responses indicate that navigating the WFDSS interface and authoring a decision is a technical skill in its own right, and that advanced training should be targeted to the relatively small number of WFDSS authors that are actively involved in authoring the majority of decisions. As one interviewee summarized:

> I think so much of that particular training, you know, you have well-meaning people or what have you, and we do too much of the, you know, throw it against the wall and see what sticks. I just think we need to be much more targeted to who gets that training, and I'm certainly not trying to be elitist or anything like that, it's just a good use of people's time, that's a good use of people's time."

5: Discussion

Summary of Findings

This research explored the use of wildland fire science and technology as it applies to DSS adoption success. More specifically, we identified factors that contributed to or hindered fire managers' perceived utility for WFDSS and gauged their preferences for WFDSS training. Our results suggest that managers find value in using WFDSS after the fact to document the decisions they make using their experience and intuition. However, several challenges including the timeliness of WFDSS outputs, the complexity of the WFDSS application, and the availability of proficient users to run the program limit the extent to which WFDSS accomplishes its intended purpose of facilitating and documenting risk-informed decision making. Fire managers perceived that WFDSS has more utility for informing decision making during circumstances where these barriers are less apparent, and there is sufficient time and people available to develop a fire management strategy using the WFDSS decision-making process. These circumstances include fires that are burning in remote areas or are not immediately threatening important values-at-risk, as well as times in-between days of large fire growth. Many of the barriers to WFDSS use reflect and extend those commonly described in broader DSS adoption literature. In the following sections we discuss how our findings relate to existing theory surrounding DSS adoption and consider future directions for WFDSS development.

WFDSS and Links to Existing DSS Theory

Many of the factors that influence the manner in which fire managers use WFDSS as well as their perceptions of benefit and satisfaction with WFDSS are interlinked (Fig. 1.3). For example, the way in which WFDSS was implemented largely to fire staff has contributed both directly and indirectly, through decreased top management support from Line Officers, to a lack of people available to run WFDSS. The lack of people available to run WFDSS increases the time it takes to develop WFDSS decisions, which leads to WFDSS outputs being used to document actions that have already happened, as well as WFDSS decisions being disconnected with on-the-ground actions. Figure 1.3 provides a visual representation of the relationships between many of our findings.

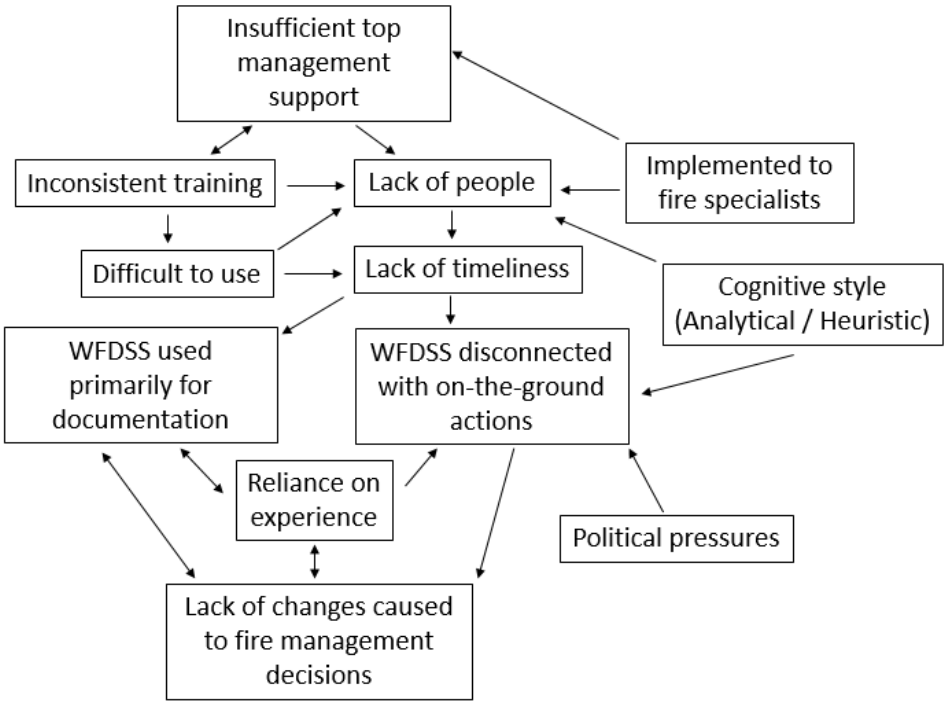

Figure 1.3. Linkage of factors influencing perceptions of WFDSS satisfaction and benefit
Many of the factors that contribute to fire manager perceptions of WFDSS benefit or satisfaction are interlinked. For example, manager reliance on experience leads them to perceive that WFDSS does not change fire management decisions, which reinforces their use of WFDSS for primarily documenting the decisions they have already made using their experience and intuition.

Our results indicate that manager experience and cognitive style influences user satisfaction and perceived benefits surrounding WFDSS. More specifically, results suggest that highly experienced fire mangers may not perceive WFDSS as a beneficial aid for decision making because they use their previous experience as the context in which they frame decision-making tasks. There is a well-documented emphasis on practical experience within the culture of fire management (Wilson et al. 2011) which prevents some decision makers from utilizing WFDSS to its full planned intent. On the other hand, some senior managers without significant fire management experience (e.g. resource specialists and Line Officers) may perceive WFDSS as useful because it helps them place decision-making tasks in a broader context that their level of experience fails to provide. Thus, our findings help bring some clarity to existing DSS literature which present conflicting results concerning the effect of experience level upon DSS adoption (Guimaraes et al. 1992) by suggesting that job-related fire experience can negatively influence DSS adoption.

Analytical decision makers may perceive WFDSS as beneficial to fire decision making because it provides an abundance of data and models that support their cognitive decision-making style. Heuristic decision makers, on the other hand, may perceive WFDSS as less useful because their decision-making style does not involve the kinds of information and processes that WFDSS offers.

Interviewees sometimes described those who were self-motivated to use WFDSS as "fire geeks." We would suggest that this alludes to the role of cognitive style differences (e.g. analytical or heuristic) in forming user satisfaction or perceived benefit towards WFDSS (Barki and Huff 1990, Green and Hughes 1986). Results suggesting increased DSS satisfaction among analytic decision makers are similar to some findings in existing DSS literature (Lu et al. 2001).

Participants indicated that elements of WFDSS design and its implementation process were far more salient to program utility, although user characteristics such as experience and cognitive style remain factors of interest. Timeliness, ease of use of WFDSS, and changes to management decisions caused by WFDSS use strongly influenced perceptions of WFDSS satisfaction and benefit. While DSS implementation literature often considers timeliness of DSS outputs as a relevant factor in adoption success (Fuerst and Cheney 1982), the time-compressed nature of fire incident decision making significantly increases the importance of timeliness for WFDSS adoption, and likely for other FMDSSs. The timeliness of WFDSS was linked to what users described as the complexity and difficulty of using the program. In the case of WFDSS, where usage is mandated by policy, fire managers expressed decreased perceptions of satisfaction and benefit because the complexity and difficulty of using WFDSS prevented them from being able to develop decisions quickly enough to be useful when fire situations changed rapidly. In that respect our findings differ and extend the "user-friendliness" or ease of use often discussed in existing literature concerning DSS usage, whereby a user is presumed to be less likely to choose to use a DSS if they find it overly complex or difficult to implement (Dulcic et al. 2012). Managers are not less likely to use WFDSS because of its complexity, but rather experience frustration with it because they are required to use a DSS that they find overly complex for the purposes of supporting decision making. We found that as WFDSS has increased in both capacity and complexity over time, the skill level required to use WFDSS proficiently and in a timely manner increasingly exceeds the abilities of many fire managers. These concerns have limited the number of users who are proficient with the program and further exacerbated the lack of timeliness of WFDSS outputs.

Our findings indicate that fire managers did not always feel that WFDSS outputs changed the course 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. Thus, our findings extend existing literature on DSS implementation to a fire context in that adoption success is closely tied to the ability of the DSS to changes decision outcomes (Bailey and Pearson 1983). Fire managers sometimes perceive WFDSS as less useful because associated decisions are often disconnected with on-the-ground actions. Many of the factors that contribute to WFDSS decisions being disconnected with on-the-ground actions

broadly relate to top management support for WFDSS and involvement in WFDSS development, which are implementation characteristics discussed in the next section.

DSS adoption literature indicates that implementation characteristics may be the most influential factors to DSS success (Alavi and Joachimstaler 1992). Similarly, our results indicate that user involvement in DSS, top management support, and training are important implementation characteristics that influence fire managers' perceptions of satisfaction and benefit with WFDSS. User involvement generally refers to including decision makers in DSS design and development, which is thought to increase a decision maker's sense of ownership with a DSS and increase perceptions of DSS satisfaction and benefit (King and Rodriquez 1981, Zinkhan et al. 1987). We define user involvement as the extent to which all managers impacted by WFDSS decisions are involved in the decision-making process. Our results suggest that a lack of user involvement decreases WFDSS adoption through its contribution to on-the-ground actions that are in conflict with WFDSS decisions. For example, if IMT members are not involved in the WFDSS decision-making process, they may prefer to pursue a strategy developed though their own assessment of operational concerns, rather than follow direction given to them through a process in which they had no involvement.

Another user involvement factor emerging from our results indicates that developing WFDSS decisions is largely performed by fire staff despite its intended use by Line Officers (e.g. district rangers, forest supervisors). Consequently, WFDSS is often seen as a fire program responsibility rather than a Line Officer responsibility. The outcome of these perspectives have far-reaching implications relating to top management support for WFDSS, a lack of people availability to run WFDSS, and decreased involvement of resource specialists with the program. For instance, our results indicate that Line Officers may not see the value in or prioritize WFDSS as much as they should because its initial implementation process included trainings that were largely targeted to subordinate fire staff. One way in which this is manifested concerns a shortage of skilled WFDSS users who are regularly available to run WFDSS, which further exacerbates previously discussed issues with the timeliness of WFDSS. The perception that WFDSS is a fire program responsibility contributes to a shortage of people available to the program because the fire staff employees who comprise the majority of proficient WFDSS users are usually busy with pressing operational concerns during fire incidents. Top management support from Line Officers that could address this issue by directing other program areas (e.g. silviculture, hydrology, wildlife biology etc.) to prioritize helping develop WFDSS decisions is often lacking. We discuss options for achieving this change in management style in the next section.

Training could improve WFDSS users' perceptions of satisfaction or benefit. DSS adoption literature consistently describes training as one of the most important implementation characteristics, suggesting that training can help overcome barriers to DSS adoption associated with several individual user and DSS characteristics (Alavi and Joachimstaler 1992, Loucks 1995). Our results reiterate and extend the importance of training when implementing DSSs by suggesting that there may have been insufficient training during the initial implementation of WFDSS, and that current WFDSS training opportunities may be insufficient in some places to overcome the evolving nature of the program. The "train-the-trainer" approach to WFDSS implementation described in our results appeared to have had varying success depending on how well the initial training prepared users to teach others. Often managers were left to learn how to use WFDSS independently as best they could through online training resources. However, this approach may not be successful for those who are not predisposed to see benefit in using WFDSS because of their past fire management experience or tendency toward heuristic decision making. Many managers lacking a solid foundation in WFDSS have subsequently struggled to keep their skills compatible as WFDSS continues to increase in complexity and capacity. Overall, it appears that some of the factors that have complicated WFDSS adoption stem from the relatively unsupported manner in which it was implemented. This example highlights the need for a robust training program surrounding complex science and technology innovations in order to maximize adoption.

Future Direction

Our results indicate that the process of completing a WFDSS decision provided many perceived benefits to resource professionals and fire managers. They reported that most of those benefits occur after a fire, including the documentation of fire management decisions, or under relatively benign fire conditions when there is enough time to assemble the right people and navigate the in-depth WFDSS decision development process. Addressing the challenges surrounding WFDSS use may help improve the utility of WFDSS decision making during more critical conditions.

Increasing training efforts surrounding WFDSS presents perhaps the largest opportunity to improve WFDSS adoption. Our results indicate that fire managers prefer advanced, in-depth training opportunities targeted towards those who frequently use WFDSS for local fire management decision making, and a support network of expert, high-level WFDSS users to provide mentorship in order to develop the skill sets of local users. It may be beneficial to target training towards improving the skillset of WFDSS Authors, who are expected to be proficient at navigating the WFDSS user interface and drafting much of the WFDSS decision content. Increasing the ability of WFDSS Authors to efficiently navigate the complex WFDSS user interface and draft decisions could improve

the timeliness of WFDSS outputs and increase adoption success as managers see WFDSS supporting real-time decision making. Furthermore, developing a geographically dispersed network of proficient WFDSS Authors could improve local training and support for WFDSS that respondents noted is currently lacking in many units. Training to build Author skillsets could involve advanced level classes or on-the-job mentorship opportunities. Mentorship programs could take the form of expert WFDSS users providing in-person support to local units during times of high fire activity, or could involve sending newly trained Authors off-unit in order to gain WFDSS experience during fire events elsewhere. In either case, it is likely that some form of cross-forest training will be required in order to share the learning opportunities available at units who experience high fire activity with units that are less likely to feature active fire seasons.

Some DSS implementation research suggests that training efforts can help moderate the effects of user characteristics and increase DSS adoption success (Alavi and Joachimstaler 1992). To this end, local WFDSS refresher trainings that involve a wide cross section of managers should thoroughly explain the underlying intent behind decision support and the value of WFDSS for improving fire management decision making. Such trainings could involve examples or after-action reviews of WFDSS decisions developed for actual fire incidents in order to demonstrate how WFDSS improves decision outcomes by complimenting the experience and intuition that fire managers possess. These interventions may increase buy-in for those who possess experience or a cognitive style that does not predisposed them to see value in WFDSS. Consequently, disconnects between WFDSS decisions and on-the-ground actions may diminish as managers see more value in WFDSS and become more likely to implement WFDSS decisions during fire incidents.

Existing literature on FMDSS has noted the importance of matching the difficulty of using FMDSS to the abilities of fire managers (Pacheco 2015, Thompson and Calkin 2011). Future efforts to match WFDSS complexity and fire manager abilities may begin by defining the acceptable timeframe for decision development, and then ensuring that a WFDSS user possessing average training and experience can successfully produce a WFDSS decision of sufficient quality within this timeframe. If an average WFDSS user is not able to develop a WFDSS decision within that timeframe (as our results suggest) then consideration may be given as to how to either simplify the WFDSS process or increase the skill level of WFDSS users through training or mentorship opportunities as discussed above. It may be that a combination of improving user abilities and reducing WFDSS complexity will be needed to make the timeliness of the WFDSS decision development process relevant to wildfire incident decision making. Additional research is needed to provide specifics as to what constitutes an acceptable timeframe for WFDSS development or determine what elements of WFDSS could be eliminated or modified in order to reduce complexity.

High-level WFDSS guidance for Line Officers should emphasize that WFDSS is a tool for them to support their decision making, with input from fire staff and resource specialists, and that it is in their best interest to support efforts to improve WFDSS use. DSS literature emphasizes the role of top management support in DSS implementation, as subordinates are more likely to adopt DSS if they see their supervisors using and promoting DSS (Lucas 1978, Sanders and Courtney 1985). Our findings suggest that increased top management support from Line Officers will be necessary to realize the changes that may need to be made surrounding WFDSS adoption. We have previously noted that the fire program within the Forest Service largely bears responsibility for WFDSS, but is subordinate to Line Officers and is lateral to the various other natural resource management programs. As such, the fire program may not have the means or authority to require that Forest Service employees from other program areas be available to run WFDSS or provide resources to enable employees to attend additional trainings. Some have observed that Line Officers increasingly lack meaningful experience with fire suppression or fire decision making (Canton-Thompson et al. 2008), which may contribute to the lack of top management support for WFDSS. Regional Offices or the Washington Office could encourage Line Officers to take greater ownership of WFDSS and hold them accountable for their role in ensuring that the training, skillsets, and people needed to complete WFDSS in a timely manner are in place.

Increased Line Officer support for WFDSS could begin by prioritizing training and requiring that resource specialists be more involved in WFDSS decision development. This would improve the availability of people to run WFDSS when fires occur because unlike fire staff, most resource specialists do not have operational responsibilities with fire management that prevent them from spending time developing a WFDSS decision. Training resource specialists to take on roles as WFDSS Authors may be particularly effective, as they often already possess skillsets applicable towards WFDSS use such as GIS, technical writing, and database management. Increasing the availability of skilled WFDSS Authors could help improve issues with the timeliness of WFDSS, which is linked to fire managers using WFDSS largely for documentation and disconnects with WFDSS decisions and on-the-ground actions.

Our results suggest that disconnects between WFDSS decisions and on-the-ground actions sometimes stem from differences between the management direction given by Line Officers through the WFDSS decision and the preferred strategies of IMTs. One way in which these disconnects could be minimized is to improve IMT participation in WFDSS. Increasing the extent to which IMT members are involved in the WFDSS decision development process may help reduce inconsistencies between WFDSS decisions and on-the-ground actions by giving IMTs a greater sense of understanding and ownership of WFDSS decisions, possibly leading to improved implementation of

those decisions. One way to better incorporate IMTs into the WFDSS decision-making process could be to increase the use of the Strategic Operations Planning (SOPL) position. The SOPL position is an Incident Command System (ICS) qualification that requires considerable previous firefighting experience as well as strong understanding and proficiency with WFDSS. SOPLs serve as advocates for Line Officers and as a communication link between Line Officers and IMTs (McHugh 2015). Units ordering an IMT should be encouraged to also order a SOPL if the IMT roster does not already include one. Leveraging the experience of individuals holding this qualification could help improve the connection that IMTs have with WFDSS and limit actions occurring in conflict with WFDSS decisions.

Finally, our findings raise questions about the utility of WFDSS as a decision support tool supporting risk-informed decision making during fires because its use by professionals is largely reactive rather than proactive, although some proactive elements exist (e.g. pre-planned management objectives from land and resource management or fire management plans). WFDSS is predominantly reactive in that the decision-making process does not begin until after an ignition occurs, requiring managers to determine what course of action is most appropriate in order to best meet management objectives. The results of this study challenge that approach in that respondents described how factors of timeliness, complexity, and lack of people make it difficult to develop a WFDSS decision at the moment a decision is needed. There may be opportunity to improve the timeliness of the decision-making process through enhanced training that increases the number of skilled WFDSS users or a simpler user interface as discussed previously, but this approach would likely face diminishing returns because time constraints will always be present. A better approach may require a shift in the way that WFDSS is used towards more proactive pre-planning for fire response.

One way to accomplish more proactive WFDSS use could be to include the Potential wildland fire Operational Delineations (PODs) concept within WFDSS as a framework for pre-planning (Thompson et al. 2016). PODs summarize some of the analysis involved with risk-informed decision making prior to the ignition of a wildfire, which could assist fire managers to quickly make risk-informed fire response decisions. PODs are geographic areas defined by possible wildland fire control features such as ridges, rivers, roads, or other features that present barriers to fire spread. A suite of various spatial wildfire risk assessments within each POD indicate whether fire occurrence would result in a net positive outcome or a net negative outcome. PODs are subsequently amalgamated into strategic response zones (SRZs) (e.g. protection, restoration, maintenance) that support objectives found in land and resource management plans (Thompson et al. 2016). The POD concept presents an opportunity to configure WFDSS in a manner that retains its beneficial components while mitigating some of its challenges. For example, incorporating spatial fire pre-

planning using the POD concept into WFDSS may streamline the process of publishing initial WFDSS decisions by reducing the amount of time spent on analysis and deliberation during the often chaotic circumstances surrounding new ignitions or on days of rapid fire growth. While the POD framework is unlikely to replace the full range of tools and processes in WFDSS, it may help fire managers leverage the strengths of WFDSS (e.g. documenting decisions with some accompanying rationale) by describing how and why the decisions they made in real time either followed or deviated from a range of response options outlined through spatial fire pre-planning. The POD concept has been implemented on some National Forests, and has been well received (Wei et al. 2018).

Conclusion

The research presented here begins to address a large gap concerning the adoption success of fire science and technology transfer efforts. While more research is needed in order to definitively say whether or not WFDSS has achieved adoption success, it is fair to say that WFDSS has some areas of utility, but also faces significant challenges to its adoption. We discuss opportunities to address these challenges through improving training and top management support, as well as modifying WFDSS to increase ease-of-use and support proactive risk-informed fire management decision making. Our findings emphasize the importance of the implementation process surrounding FMDSSs adoption and show that the broader literature surrounding DSS adoption is largely applicable to FMDSS efforts. As FMDSS continue to proliferate, future efforts to implement FMDSS should consider the results of this study as well as DSS adoption literature as a whole in order to maximize adoption success.

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APPENDIX A: Interview Protocol

- What is your job title, briefly describe your job duties for me. How long have you been in that position?
- What is your experience with using WFDSS?
    - I have your user role(s) listed as _____, does that sound correct?
    - Which role do you use the most?
    - Other classes?
- How confident do you feel using WFDSS?
- Describe what components of WFDSS do you find useful?
    - Information, situation, assessment, objectives, course of action, cost, decisions, periodic assessment, reports.
    - Why do you find those components most useful?
- How useful is WFDSS in guiding fire management decision making?
- What, if anything, would you change about WFDSS?
    - How about the design of the program? Content? Ease-of-use?
    - How would your suggestions improve the program?
- How did you learn to use WFDSS?
    - How about the S classes?
    - Webinars?
    - Conferences?
    - WFDSS 101 / WFDSS Help?
    - Geographic Area Editor Trainings?
- How well did your trainings prepare you to use WFDSS in the field?
    - Where there any trainings that were particularly useful?
- Where do you go when you need help with WFDSS?
    - What resources are available to help use WFDSS?
    - WFDSS help desk? WFDSS website?
    - How often do you use that content?
    - How about your peers or supervisors?
- Given your experience, what types of training do you wish had existed when you first started using WFDSS?

- How would you like those trainings presented?
    - Online or in-person
    - What website / platform?
    - Workshops?
- What are the best ways push out trainings about WFDSS?
- Have you heard of the RD&A? How has their content been useful to you?

** S-495 Class Specific Questions (if applicable) **

- What is your highest level of education? What is it in?
    - Undergraduate, Graduate
- What is your GS level?
- What is your background in fire management?
    - How much experience have you had in
        - Primary: SMKJ, IHC, HELI, WFM, HC, ENG
        - Secondary: FUELS, PREV, DISP, A/FMO
        - Collateral Duty: MILITIA / AD
- What red card qualification have you held (current and expired)?

S-495 Class Specific Questions

- Why did you take S-495?
- How comfortable would you feel running WFDSS fire behavior analysis at your home unit?
    - How will S-495 material help you in your job?
- What were you were expecting to learn from this class?
    - What elements of this class helped meet those expectations?
    - What elements of this class were detrimental in meeting those expectations?
- What information formats did you find most helpful in S-495?
    - PDFs? Videos, scenarios, lectures
    - What other case studies or scenarios would you like to see in the class?
- How well did instructor examples help you understand the materials in this class?
    - What worked best and what didn't?
- What opportunities did you have to practice what was being taught?
    - Describe the feedback you got from class.
    - Would you rather have more, smaller case studies or fewer, large project case studies?
    - Did that change between online and in-person?