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In This Issue

Articles in this issue of *Fire Management Today* examine the current status of fire doctrine and how it fits within evolving efforts in risk management. They discuss the benefits of reporting and learning cultures within the Forest Service organization and expound on the role that a "Just Culture" plays in the process of raising the mindset of our organizational safety culture.

Articles highlight how these new relationships, safety management systems, and innovative learning tools are becoming integral parts of this shift in emphasis. They provide new perspectives on learning from accidents and near-misses through the emergence of new findings in human factors and human performance that go beyond the static view of human error. Risk management and fire doctrine highlight how individual and organizational behaviors can generate more beneficial outcomes for the mission as well as the organization.

Many thanks to Mike Apicello for coordinating many of the articles in this issue.

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Risk management is critical in both air and ground operations. Here, the Chester Flight Crew heads out from the Dammeron Fire, St.George, UT, 2005. Photo: Bobby Griffith, Lassen National Forest.

The USDA Forest Service's Fire and Aviation Management Staff has adopted a logo reflecting three central principles of wildland fire management:

- *Innovation:* We will respect and value thinking minds, voices, and thoughts of those that challenge the status quo while focusing on the greater good.
- *Execution:* We will do what we say we will do. Achieving program objectives, improving diversity, and accomplishing targets are essential to our credibility.
- *Discipline:* What we do, we will do well. Fiscal, managerial, and operational discipline are at the core of our ability to fulfill our mission.

Firefighter and public safety is our first priority.

ANCHOR POINT

by Tom Harbour
Director, Fire and Aviation Management
Forest Service, Washington, DC

A Century Later—How Does the Tale End?

Last August, I stood in a cemetery in remote Wallace, ID, commemorating the 100th anniversary of the 1910 “Big Burn,” a fire that burned more than 3.1 million acres (1.3 million ha) across northern Idaho, western Montana, and eastern Washington, and took the lives of scores of people—many of them firefighters just like you and me. Eight communities were incinerated. The 36-hour fire siege was “ground zero,” the “9/11” of their time. At least 85 people died; more than 70 of them were firefighters. The entire country was shocked and outraged as they mourned the loss. The fires left in their wake a stunned Nation, a changed political climate, and a call for the support and protection of the people and their public lands.

Who We Were

Then, we were a small, fledgling organization, working on behalf of the citizens. There was little training available and even less support. Basic qualifications were nonexistent other than the ability to work hard. The experience gained as a firefighter in those days was generally through the “school of hard knocks”—and no one or nothing knocked harder than what happened in 1910.

Who We Are

During the past century, the Forest Service reinvented itself. As veterans of the 1910 fires, the next three successive agency chiefs understood that fire was the key to that reinvention. The Forest Service developed fire suppression expertise and cultivated fire research and cooperative fire protection programs. Congress passed laws, the U.S. Department of Agriculture developed regulations, the Forest Service developed policy, and the Administration provided funding. Through individuals such as Ed Pulaski, Joe Halm, and William Weigle, we learned the value of leadership, crew cohesion, and the need for physical fitness, woods savvy, and situational awareness. For more than 100 years now, we have done our jobs and done them well. We have evolved using the expertise we’ve developed, and, today, we have the reputation of being the best firefighting organization in the world. Together with our predecessors, we’ve shaped that reputation.

Who Do We Wish To Become?

The question today is: “What will folks in 2110 say about our efforts?” This Nation has been built on folks “pulling their load” and “doing their part.” Yet, even with all we have now—what we’ve learned over the past 100 years—the complete solution to the Nation’s wildland fire management problems continues to evade us. Our woods are too dense and our weather, too severe; there are too many homes and people in close proximity to our wildlands. We know if we don’t make changes *together* as a Nation, the future is bleak. We face a wicked, difficult problem.

The National Cohesive Wildfire Management Strategy

Last November, when Congress passed the Federal Land Assistance, Management, and Enhancement Act of 2009 (the FLAME Act), it offered us an opportunity to build upon many of the other good, collaborative work we’ve accomplished over the past decade. Congress asked for the creation of a cohesive wildfire management strategy to address the complex problems that face us.

Recognizing that we cannot solve the wildland fire management problems facing the Nation alone—that it is not our fight alone—the Secretaries of Agriculture and of the Interior sought the assistance of other Federal, State, tribal, and local governmental and nongovernmental partners to create a cohesive nationwide wildfire management strategy. We are hopeful that this strategy and the framework it is built upon will help us work more effectively as firefighters and managers of *all lands* across this United States of America. Once implemented, the national strategy will enable us, collectively, to promote more resilient landscapes and communities that are able to co-exist with wildland fire and will strengthen our response efforts. Through this national cohesive strategy, we—the Forest Service firefighters and fire managers—will continue to do our part. Then, we will be fire management leaders.

How Will the Tale End?

Many years after the fires of 1910, Ranger Joe Halm wrote: "More than three decades have passed through the hour glass of time, and nature has long since re-clothed the naked landscape with grass, shrubs, and trees, but the great sacrifice of human life is not, can never be, replaced or forgotten."

Perhaps 1910 was the tragic beginning to a tale, but the end of the story can yet be better. The tale is ours to write and should be built upon the experiences and sacrifices of all firefighters who have gone before us: those we can never forget. The firefighters of the past pulled their load—they did their part. Today, we need to honor their sacrifice and look to the future, commit to doing what is necessary to learn and improve. Future generations are counting on us to be the leaders that the world has defined us to be. Together, we can do more than we can alone; we owe it to ourselves, our profession, and the American people. ■

View of the tunnel where men lost their lives in the 1910 Fires. Coeur d'Alene National Forest, ID. Photo: R.H. McKay, 1910.

Moving Toward a Coherent Approach to Safety and Risk Management

Mike Apicello

When Fire and Aviation Management (FAM) adopted the principles of doctrine in 2006, it embarked on a journey that many thought would take decades to accomplish. Although many felt that the 2005 Pulaski conference in Alta, UT, set the tone for an organizational shift to a more safety-conscious fire culture, others believe that the real impetus was the 1994 fire season, in which 34 lives were lost. After the 1994 fire season, numerous policy and programmatic reviews were conducted. When it was released, the Interagency Management Review Team Report on the South Canyon Fire spelled out more than 180 action items for improving firefighter safety and fire program management. Yet, even after a decade, many unresolved questions about firefighter safety still lingered until the Pulaski conference was convened and the principles of modern fire suppression doctrine were revealed.

There are a few observers who still question whether the "sense-making" concepts that circulated freely during 1994 were incorporated into the modern "decisionmaking" aspects of current doctrine. It remains unclear when the real cultural shift to current doctrine began, but doctrinal changes are here. Modern fire management doctrine is alive and well.

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Several notable achievements with doctrine today are listed below. Some pertain to the operational aspects of fire suppression while others focus on fire management program areas. In both cases, they highlight current doctrine, its relation to safety management, and the rise of a coherent safety culture. In addition, articles within this issue present specific examples of key principles central to both the evolutionary doctrine and risk management programs that are at work today. Each achievement represents another step in this journey.

The Branch of Risk Management took on the charge to promote a "learning" culture within FAM.

Changes Captured in Doctrine

Restructuring

The FAM program has restructured its traditional, intuition-based fire safety program to a more exacting, science-based program for managing risk. As part of this, FAM created the Branch of Risk Management, Human Performance, and Development (generally referred to as the Branch of Risk Management). FAM challenged the Branch of Risk Management to find new ways to "anchor" safety in an organizational mindset focused on aggressive risk management and human factors principles.

Promoting Learning

The Branch of Risk Management recognized that valuable lessons could be learned by looking at near-misses as well as accidents, and so took on the charge to promote a "learning" culture within FAM. The branch also developed the concept of a "reporting" culture: one that could shift away from a reliance on blame and help blunt the stigma put on people involved in serious accidents and fatality events. As a result, new learning tools were developed: both the Accident Prevention Analysis (APA) and the Facilitated Learning Analysis (FLA) are in widespread use today and are contributing significantly to organizational learning.

Partnerships

In a relatively short span of time, the branch also developed robust partnerships with the Rocky Mountain Research Station, the Wildland Fire Leadership Development Program, and the National Incident Management Organization (NIMO). These unique relationships utilize the best research and science available to promote knowledge and understanding in the fields of human factors, leadership development, and risk assessment. As a result, these efforts continue to maintain our FAM program as one of the best high-reliability organizations involved with modern wildland firefighting.

Empowerment, Responsibility, and Accountability

Doctrine deals with the issue of discretionary powers, especially in how they pertain to decisionmaking. When doctrine was first adopted, many people thought that the rules of engagement were being relinquished. Some even thought that the 10 Standard Fire Orders and 18 Watch-Out Situations were being abandoned! This is far from the truth. The operational intent of doctrine is to empower decisionmaking and heighten situational awareness: it does not remove anyone's responsibility for sound judgment or accountability for decisions. Although the doctrine empowers people to use their own judgement to make better decisions "at the sharp point of the spear" (where accidents most often occur), it keenly recognizes that, where there is increased empowerment, there is also increased responsibility and accountability.

> Fire suppression doctrine recognizes that, where there is increased empowerment, there is also increased responsibility and accountability.

The Journey Into Procedure

Direction

As soon as the doctrine was officially adopted by the agency, personnel from the Branch of Risk Management started working with the Forest Service Office of Regulatory and Management Services in Washington, DC, to significantly revise chapters 5100 (Fire Management) and 5700 (Aviation Management) of the Forest Service Manual (FSM). Although the revisions have taken time to complete, efforts remain on track, with the final revisions due in 2011. The revisions are tiered to the doctrine's grass-roots evolution: much of the input that influenced the FSM revisions has been supplied by the field, where revisions have their strongest application and need.

The FSM revisions also reflect a key shift toward fostering a shared safety culture with our cooperators. This change is reflected in the revision of the FSM 5720 (Aviation Safety) chapter. Revisions in this chapter detail specific shifts in cultural procedures. They are outlined in Ron Hanks' article, "Implementing Management Systems for Aviation Safety," in this issue.

Safety Management Systems

Revisions to doctrine enabled the adoption of Safety Management Systems (SMS), a fully comprehensive and progressive safety program used extensively by the international aviation community. SMS is unique in that it adds components to our existing aviation safety programs that establish high levels of quality assurance and uniform safety standards across the entire interagency firefighting arena.

SMS is a proven program with a tremendous potential for risk reduction. As many of the aviation platforms used in wildland firefighting come directly from the aviation industry, SMS connects both the operators and providers of these resources directly to our own incident management personnel and firefighters on the ground. Shared accountability, quality assurances, risk assessments, and proactive safety promotion are paramount components. For more detailed information on SMS, see Ron Hanks' article in this issue.

Organizational Learning

Two new innovative tools with distinct roots in doctrine are the APA and the FLA. Both of these tools support learning from unintended consequences and promote cultures that share or report information. Both the APA and FLA demonstrate how decisionmaking under pressure can influence incident outcomes.

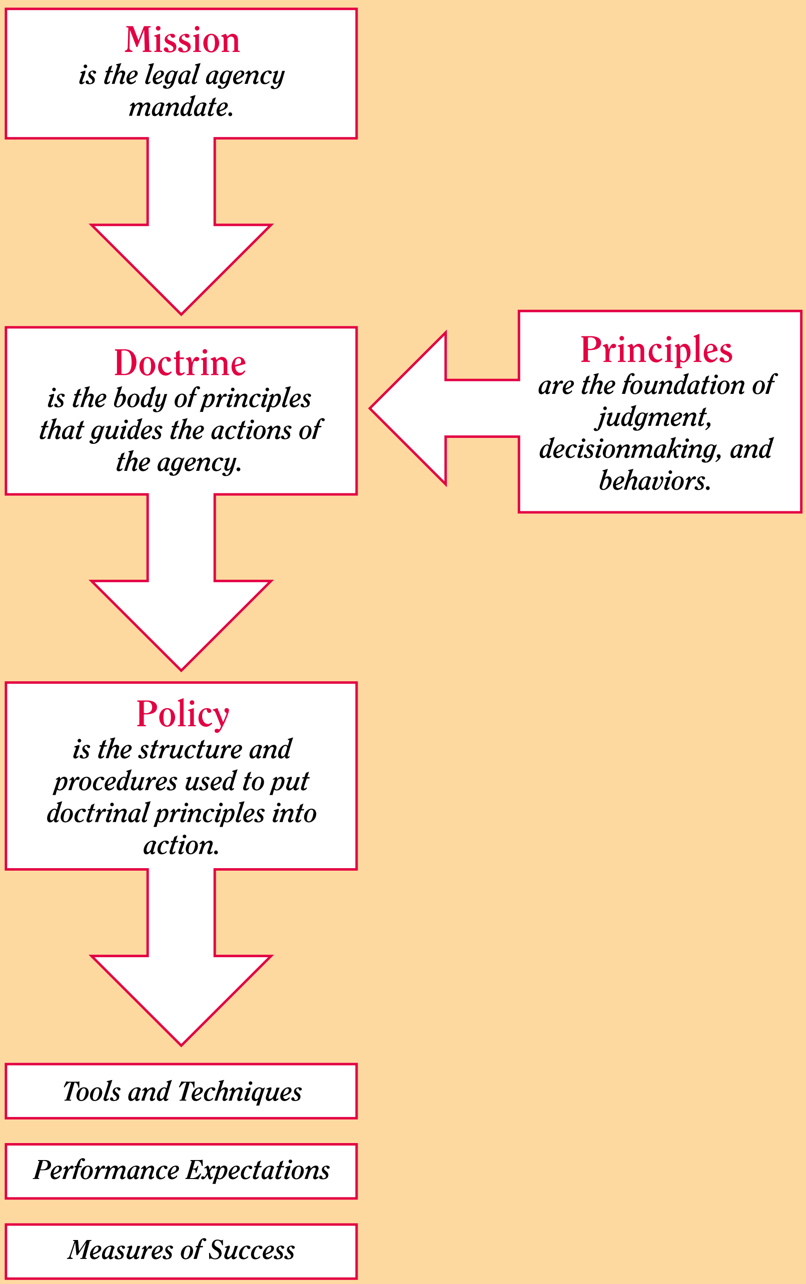
When these tools are used as intended, people tend to communicate openly on what they were thinking during risk assessment and how they reacted to the consequences of their decisions. The information gleaned from these events serve as invaluable "lessons learned" when they are shared and help prevent similar events from occurring again. Because APA and FLA were designed to have universal application, they can help disseminate vital safety information in a timely fashion.

APA and FLA analyses are conducted under the spirit of a Just Culture through innovative "storytelling" techniques. They work on the premise that people will be more open to communicating mistakes if the fear of reprisal is removed and if they are allowed to describe what happened from their own unique perspectives. Understanding how the APA and FLA processes work helps firefighters to learn from unexpected outcomes. Lessons learned from a number of APA and FLA reports are available at the Web site <http://www.wildfirelessons.net/documents/>.

Fire Suppression Doctrine: Finding the Niche Between Forest Service Mission and Policy Implementation

Doctrinal principles of wildland fire suppression described in this article are based on well-defined agency values and act to transform assumptions about agency values into facts. From the principles of doctrine come the strategies and tactics for achieving the agency mission, the tools and techniques for executing those strategies, and defined expectations of behaviors.

Forest Service Fire and Aviation Management is an organization guided by well-stated doctrinal principles, which represent the reality of the work, the environment, and the mission of the Forest Service. Doctrinal principles are the heart of safe and effective mission accomplishment.



APA and FLA reviews are not mandatory, nor are they required by policy. They exist solely for learning purposes and are an essential part of any learning or reporting culture. Lessons learned contribute to an organization's knowledge base and serve to promote safety culture.

People will be open to communicating mistakes if the fear of reprisal is removed and if they are allowed to describe what happened from their own unique perspectives.

Just Culture and Doctrine

Some people say that Just Culture is critical to the implementation of current doctrine; others feel it is too unwieldy to implement in a rules-based organization. Discussion of the term and its application must begin with a definition of Just Culture.

Just Culture is a human factors-based safety system for principle-centered management. Principle-centered management does not seek rote compliance with procedural rules but rather a risk-based, intelligent, and creative application of fire management principles.

A mature learning organization recognizes that creating a system for reporting errors and then learning from them are essential processes for any safety-based culture to maintain forward momentum and growth. With current doctrine, reporting and learning are also essential for risk recognition and hazard mitigation. Just Culture helps to encourage the sharing of information and recognizes it as essential in a learning culture. For a more comprehensive description of Just Culture and how it is being used today, see Steve Holdsambecks' articles, "Just Culture: Effective Accountability for Principle-Centered Management, Parts 1 and 2," in this issue.

Human Behaviors vs. Human Error: A Doctrinal Perspective

Is "human behavior" the same as the "human factor" in accidents? Larry Sutton's article, "Common Denominators of Human Behavior on Tragedy Fires," looks beyond findings of "human error" in traditional investigations of serious accidents. This article takes a doctrinal perspective and describes how human behavior can also prevent errors. In terms of doctrinal or risk management principles, Sutton's article provides insight into why human *behavior* is important for the influence it has on decision-making and its outcomes.

Moving Forward

It's no secret that the new doctrine is changing some of our traditional wildland fire thinking. We are seeing innovations and new ways of doing business that we never dreamed of in the past. "All flaps are up" on this journey to improve firefighter safety. And, where there is improvement, there is always hope. Contributors to this issue hope to promote a better understanding of what it takes to build a safety culture in fire management.

For an introduction to the concept and components of current doctrine, see <http://www.fs.fed.us/fire/doctrine/index.html>. ■

Just Culture Part 1: Effective Accountability for Principle-Centered Management

Steve Holdsambeck

How managers and supervisors react to an accident can either move the organization toward or away from a learning culture. In this regard, a "Just Culture" cultivates a learning culture. Traditionally, we have approached accidents the same way as we look at crimes: as an event that something (typically someone) actively caused. Crimes are committed and accidents are caused, and someone needs to be held accountable. This isn't fair or just. Accidents (or "unintended outcomes") are not crimes, and a Just Culture will not treat them as such.

Blaming the Victim

With perfect hindsight, accident investigators can practically always find human decisions at fault at a crucial point in any accident story. Starting with the outcome and working backward in time, any competent investigator will sooner or later isolate a group of decisions that, had they been made differently, would have avoided the tragic outcome. These decision points are collected and tabulated (just as evidence from a crime), and the salient ones are labeled "findings," giving them the status of truth, regardless of context. Accident investigation teams often bring in subject-matter experts to elaborate upon decisions that constituted procedural violations in a specific functional area. Decisions that were made or that should have been made differently become *causal* factors.

Steve Holdsambeck is a fire operations safety officer for the Forest Service, Intermountain Region, in Ogden, UT. Much of the information in this article is taken from his work on the Accident Prevention Analysis Guide (USDA 2010). Holdsambeck has been advocating the adoption of a Just Culture in the Forest Service through lectures and writings since 2005.

Hindsight, by nature, can actually invent reality. Some of these decisions are seen as *should-have-done-differently* only *because* an accident occurred! For example, the old Fire Order "Fight fire aggressively having provided for safety first" was frequently taken to be violated by the very occurrence of an accident. Obviously, the employee did *not* provide for safety first or the accident would never have occurred.

Hindsight is also selective. Sometimes, we've blamed people for causing an accident because they weren't paying attention to something we can see only after the fact. The amorphous concept of "situational awareness," according to many accident investigations, can easily be lost, and losing it can itself be a contributing cause of an accident. If we look at accidents as events that people caused (as we say "a crime was committed"), then our accident investigations will reinforce the false reality that the system (or workplace) is safe until humans (such as our employees) make it otherwise.

> Any safety system depends crucially on the willing participation of the workforce, the people in direct contact with the hazards. To achieve this, it is necessary to engineer a reporting culture–an organizational climate in which people are prepared to report their errors.… An effective reporting culture depends, in turn, on how the organization handles blame and punishment.… What is needed is a Just Culture.
>
> —James Reason (1997)

The Consequences of Blame

Blaming employees for causing accidents has not worked well for the wildland fire community. We have sacrificed a *learning* culture to a superficially *accountable* culture. In the wake of an accident, sometimes we punish firefighters and sometimes we don't, but we have consistently found ways to blame them for the accident.

Blame is often worse than punishment. Due to privacy rule interpretations, punishments often are held confidential. The human *cause,* however, is typically published in the accident investigation report,

> Every system is perfectly designed to achieve exactly the results it achieves.—Donald Berwick

and, though the names of involved parties may be redacted in the report, in the small and familial wildland fire community, everyone soon seems to know who is blamed for losing "situational awareness," ignoring the fire order, or violating a standard procedure.

Blame is powerful and consistently effective in one respect: it acts to suppress the disclosure of behavior that might be considered blameworthy. In a sense, we have implemented a system to suppress both the reporting of mistakes and the understanding of how our employees normally make safety and risk management decisions in the field.

Forward-Looking Accountability

Sociologists tell us there is something intrinsically and darkly satisfying with retributive justice. The subject line of the email that spread the news of the conviction and death sentence of the arsonist convicted in the Experanza fire throughout the Forest Service was titled simply: "Justice Served." Like revenge, retribution carries with it the comfort of closure, the isolation of responsibility, and the assurance of personal innocence. We'd rather know the criminal was punished than know why he committed the crime.

But accidents are different than crimes, and it is unjust to treat employees who are involved in an accident as perpetrators. In fact, our criminal justice model is wholly antithetical to a safety culture as it focuses on after-the-fact retribution in backward-looking accountability. A human factors-based approach to accidents will recognize that human performance is as inevitably variable as the risks in a wildland environment.

> Take your pick; you can blame human error or you can try to learn from the failure.
> —Sydney Dekker (2006)

There are many facets of a Just Culture, but one of the most salient is that all employees are held accountable *fairly* for their participation in, and contribution to, the safety of the organization. This means that managers have unique and, in some respects, much higher responsibilities. For example, one of the most important and powerful responsibilities lies in choosing how to respond to unintended outcomes. The choice (either to learn from the mistakes or to punish the mistakes) can vector the agency toward, or away from, a learning culture.

Focusing on the future and taking action based on the lessons learned, to change procedures so that future accidents are less likely, is "forward-looking accountability" (Sharp 2003). For learning and improvement to be sustained, leadership must protect and cherish those employees who are willing to raise their hands, stand up, and say: "I was involved in that accident. Here is what I saw, here's how I made sense of it, and here's what I've learned." This protection is part of the justice of a Just Culture.

Taking this approach, the best thing we can do is to learn continuously from situations in which we have made mistakes, misjudged or underestimated risks, or put employees into situations in which inevitable human fallibility is an unacceptable risk. The best we can hope for is that, if we learn from the past, we can change, and the future will be better.

An Inconvenient Truth

Another feature of a Just Culture is that it protects employees when they speak honestly about competing and often irrational operational goals. For instance, *safe, effective, and efficient* are laudable principles, but as operational goals, they are inherently conflicting. The more emphasis is given to one, the more the other two will suffer, and a struggle to implement all three equally would lead to socially intolerable compromises to safety.

Likewise, administrators, safety officers, and other leaders who assert a "zero–tolerance" policy toward accidents are less effective than they could be because they are not working within reality. Wildland fire organizations do not exist solely to be safe: they exist to accomplish work, and that work **necessarily** entails accepting risks and their consequences. Within a Just Culture, administrators are ultimately responsible for decision-making, but employees participate in determining how competing goals will be balanced, how risks will be managed, and how the level of acceptable risk is determined—knowing that, when risk is accepted, so is the likelihood and severity of its consequences.

Turning Hindsight into Foresight

A wildland firefighter's world is dense with ambiguous and unexampled situations. Frequently, there can be potentially dangerous circumstances that fall outside of the textbook, training, and past experience. A Just Culture, like the current fire suppression operations doctrine, recognizes that wildland firefighters **must** improvise as they negotiate between the competing goals of safety and production. Indeed, operational risk management involves **creative** responses to changing circumstances and competing goals. Unfortunately, the distinction between creatively managing conflicting goals in ways that reduce risks (emphasizing safety), and creatively managing conflicting goals in ways that increase risks (emphasizing production), is only made in the hindsight of an unintended negative outcome.

A backward-looking approach is incompatible with a forward-looking approach, as hindsight can sabotage a Just Culture. The deciding question facing us is: which is more important?

A. Understanding how it made sense to our employees to:
   - See things the way that they were seen,
   - Expect what was expected,
   - Believe the risks were one way, when—*in hindsight*—we know they were another way,
   - Forgo an available hazard mitigation,
   - Shortcut typical procedure,
   - Accept a risk that—*in hindsight*—seems unreasonable to have accepted, or
   - Ignore a risk that—*in hindsight*—seems so obvious;

or

B. Blame each particular mistake or person that makes the error.

A Just Culture's answer to that question is unequivocal: *learning trumps retribution*. What made sense to one employee might easily make sense to another unless we change the conditions (culture, training, latent conditions, etc.) under which our employees are working. Punitive actions remain sensible tools for correcting actions that are reckless, malicious, or dishonest or violations of procedural rules that continue even after employee counseling. However, programmatic discipline under the guise of employee accountability can actually be a very dangerous policy. If we punish mistakes or blame the error-doer, the only guaranteed outcome will be that managers will find out about fewer mistakes.

Moving Toward a Learning Culture

Just Culture is the foundation of a reporting culture and a learning culture. The more developed a Just Culture is in an organization, the better that organization can learn from past events and the more resilient that organization will be in facing future risks. Inherent in a Just Culture is the appreciation that system designers must account for the human element in that system. They must accommodate employee fallibility and take advantage of their counterbalancing creativity. Just Culture recognizes that there is always a gap between work as imagined by the administrators and system designers and the process and procedures used as work is actually performed. Under the protection of a Just Culture, this gap can be discussed and exploited for its high value in refining and improving risk management.

In Part 2 of this article on Just Culture, we will examine the meaning of "safety," "risk management," the gap between work as imagined and work as done, and the further definition of Just Culture.

Just Culture: A Definition

Just Culture is a human factors-based safety system for principle-centered management. Principle-centered management does not seek rote compliance with procedural rules but rather risk-based, intelligent, and creative application of fire management principles.

A Just Culture uses principle-centered management to increase system reliability in two ways. First, Just Culture provides the essential *safe room* for dialogue to discuss—non-punitively—decisions, errors, mistakes, and hazards, and most importantly, to examine individual and cultural values that guide risk management choices. Second, Just Culture distributes accountability as it holds that management must be able to support a culture of safety in the workplace even as it manages employee independence. For more information, see <http://www.justculture.org>.

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Common Denominators of Human Behavior on Tragedy Fires

Larry Sutton

On my desk is an original copy of the pamphlet published in 1978 titled "Some Common Denominators of Fire Behavior on Tragedy and Near-Miss Forest Fires" by Carl C. Wilson and James C. Sorenson (USDA 1978). Although the Incident Response Pocket Guide (IRPG) (NWCG 2010) discusses the four major common denominators in a single page, the original pamphlet used 31 pages to address the topic.

Like many of our historic documents, much of the thinking included in the Wilson and Sorenson work is just as applicable today as it was when it was published. For example, 32 years ago, these authors wrote: "The potential for loss of life in forest fires, due to burns or other fire-induced causes, is higher now than ever before. Many people live in or play in the wildlands. As a result, "protection of life and property" has begun to dominate fire suppression action plans. The relative safety of "perimeter fire strategy" must often be sacrificed in favor of people and their possessions. This puts forest-fire agencies at a disadvantage, because most training in the past has concentrated on perimeter strategy." Those words might as easily have been written yesterday.

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It's extremely useful to identify common denominators of *fire* behavior. What about *human* behavior?

The Human Focus

Although today we typically talk about the "common denominators" of tragic fire incidents as a short list of weather, fuels, and topographic characteristics shared by fires that blew up and killed firefighters, the original denominators pamphlet covered other ground. On one page is a drawing of a firefighter with a big question mark where facial features should be, and the accompanying text reads: "The external signs and warnings are important, but the internal state of the firefighter is also important in tragedy and near-miss fires. Even well-trained firefighters are often unaware of a dangerous situation until it is too late." Again, we hear truth from the experts of another era in our profession.

While it's extremely useful to identify common denominators of *fire* behavior, what about *human* behavior? Are there any common denominators of human behavior that can be identified, at least when a tragedy was related to fire behavior?

In most fire-related accidents—at least in ground fire operations—human behavior plays a crucial role. An accident investigator can't point to a mechanical part and say: "There, you see: that's what caused this accident!" No, our accidents are much more complex than that, and attempts to list causal and contributing behavioral factors for such accidents have largely failed for a number of reasons.

For one thing, unlike a mechanical part, humans do not always "fail" in the same way under the same set of conditions. Applying the scientific method requires three basic steps: observation, hypothesis, and testing; the testing phase requires repeatability—in other words, the same set of conditions should generate the same results every time the experiment is conducted. This repeatability simply doesn't exist with human behavior and is the prime reason that mechanistic analyses of human behavior are misguided. Furthermore, because behavioral "failure" is a subjective judgment based on hindsight, we might as well eliminate that term from usage in reference to human behavior.

Variability in human behavior and situational creativity are responsible for both our greatest successes and our tragedies. The operational context in which behavioral variability is expressed also changes constantly: the same basic set of decisions and actions might lead to a successful outcome in the morning and tragedy in the afternoon.

Identifying the Common Denominators

A wide range of human behavior has been observed on many different fires, in different locations, and under various conditions. Might there be some benefit to wildland firefighters if we could identify and understand some of the "common denominators of human behavior on tragedy fires?" Could recognition of these factors during an operation increase the chances of a safe outcome?

The authors of the original "common denominators" were wise in recognizing that no list or group of concepts can be considered definitive and all-inclusive in an environment as dynamic as wildland fire. At one point in the 1978 pamphlet, they admonish readers to "remember that all fires differ and that the change of one small factor can result in an entirely different picture." They also give a nod to the significant role played by human behavior in determining whether an outcome was a tragedy or a near miss: "Whatever the reasons, individual behavior and circumstances make the difference between life and death." While that's certainly true, simply knowing that may not make us any safer on a fire.

The following list can't be considered to cover every situation on every fire. But these things come up often enough in accident reports and analyses of near misses to indicate they are worthy of being considered common denominators of human behavior on many of the wildland fires in which we've lost firefighters. And just maybe, they could apply to fires that haven't happened yet, where we also might lose firefighters, which is why they're worth thinking about.

The common human denominators:

- **Effective communication is absent or impaired.** This has to do with communication among subordinates, peers, and higher level leaders. It could easily be a hallmark of any failed operation, on or off the fireline. The importance of communication is expressed in the "C" in the "LCES" (Lookouts, Communications, Escape Routes, and Safety Zones). Barriers to communication are not always physical or technological: in many of our past fatalities, radios worked well and, in some cases, there was even cell phone coverage. Effective communication in this context has more to do with how communication can serve collective situation awareness and how firefighters need to recognize and mitigate barriers to communication—for example, between types of crews or between ground and aviation resources.

  Many assumptions regarding roles and responsibilities are made during any communication. Page *ix* of the IRPG addresses firefighter responsibilities for effective, ongoing communications.

- **Clear direction is not provided by management or incident commanders.** This direction could come from management or the incident commander on objectives, time frames, and availability of additional resources. There are two key aspects to this factor. First, have clear objectives been articulated? And second, were those objectives clearly communicated to those who needed to know? The leader's intent guidance on page *ix* of the IRPG addresses task, purpose, and end state concepts for mitigating potential misunderstandings of this common denominator, and the briefing

The spot where Joseph Sylvia fell on the Mann Gulch Fire, Helena National Forest, Montana, 1949. Which human denominators were present on this or any other historic fire you have studied? Photo: Larry Sutton.

checklist inside the back cover of the IRPG is useful in communicating intent.

There are also some finer points to be made here: are the objectives provided only tactical, or are there some strategic objectives that should be communicated as well? For example, is "Keep the fire north of this road" a sufficiently complete objective? Sure, it's measurable; but what happens if it can't be achieved? Unless the manager or incident commander is present at the point of friction, firefighters will have to devise new objectives on the fly. These new objectives may or may not be aligned with the leader's intent unless the overall objective has been clearly stated beforehand, with enough leeway to allow for changing conditions.

- **Continued attempts to achieve objectives that are not achievable.** The objectives might have been achievable earlier, but at some point they're no longer viable due to current fire behavior or availability of firefighting resources. This denominator is huge: in most accident reports, it practically leaps off the page. This assessment may be due to hindsight bias: the authors and readers of such reports know the outcome of tactical efforts, insights that firefighters at the time of action clearly did not have.

  In recent years, it has become fashionable to refer to firefighters' "loss of situational awareness" as an explanation for why they missed some important environmental cue. But such assessments tell us nothing of actual events and can lead to few useful conclusions. For one thing, awareness can only deal with immediate surroundings, and as to awareness beyond what is observed or communicated, it's impossible to lose something you never had in the first place. Furthermore, some human factors experts believe that the only way to literally lose situational awareness is to become unconscious: while awake, people are always aware of something.

  The more pertinent questions are: What is the focus of your awareness at any given time and why? Saying a firefighter lost "situational awareness" is the same as saying the firefighter made a mistake. We don't learn anything from this type of after-the-fact judgment that would prevent a similarly trained and experienced firefighter in the same situation from making exactly the same mistake!

  The concept of "plan continuation," that firefighters doggedly stick with a plan even in the face of growing proof that it's going to fail, is also cited as a factor in some accidents. And yet, that same stubbornness in sticking to a plan and executing it, even against intimidating conditions, is a highly valued characteristic of firefighters in most situations. There are likely cultural aspects to this factor as well: firefighters—and especially leaders of firefighters—don't like to admit that their initial plan has failed or all their hard work was ultimately for nothing. Perhaps firefighters at all organizational levels need to get better at analyzing and revising objectives in the face of changing conditions. Perhaps we need to understand that we have more options than simply ordering more resources and hoping that they show up in time to do some good.

- **Potential for rapid change in environmental conditions is not recognized.** Such changes must be anticipated and planned for continuously throughout an operational period. At least half

Which of the common human denominators will be present on your next fire? Photo: Larry Sutton, on the Salmon-Challis National Forest, Idaho, 2007.

of the Standard Firefighting Orders are intended to help mitigate this issue, for example, "Keep informed on fire weather conditions and forecasts" and "Post lookouts when there is possible danger." What's interesting in evaluating past decisions in the field is that, even on fires in which firefighters clearly were aware of hazardous weather and fuels conditions, they took (in hindsight) extensive risks anyway, often during the most dangerous part of the burning period or after their fire did something spectacular nearby.

We don't seem to know why this happens. Were firefighters actively engaged in convincing themselves that the impossible was possible? That they could accomplish their plan when most neutral observers would say "No way"? Or were they just intent on doing something because, well, that's what they're there for—to do something?

What role does fatigue play in this absence of reassessment and response? If you're tired, is it easier to miss small environmental cues or overlook the fact that your escape route is longer now than it was 2 hours ago? Actually, there is no "if you're tired" on a fire. Fatigue is a constant even if you are fit and meet the 2:1 work/rest requirements.

The critical fact in all operations is that, in real time, we are only capable of acting with foresight, never with hindsight. We only get to make decisions with the information we have at the time. Perhaps we can avoid many hazardous situations if the potential "worst case scenario" is constantly kept at the forefront of our thinking. This is exactly what many of our most seasoned practitioners do on a routine basis and why the "High Reliability Organizing" principle of "preoccupation with failure" makes intuitive sense to most firefighters.

> The disciplines of social science and psychology may have much to offer us in terms of insight into how the firefighter's mind functions under stress.

The Goal

It's possible to have all of the necessary conditions in place on a fire for a tragic outcome and not have it occur—for example, when a crew is not communicating effectively with other units but no harm results. This probably happens far too often. Such an outcome can only be called "good luck," but most firefighters would rather be good than lucky.

While many individuals are involved in wildland firefighting operations, we don't really know much about how the human mind works when on the fireline. Which actions are intentional or conscious, and which actions are automatic or unconscious? How much of what we do is analysis, and how much is intuition? The disciplines of social science and psychology may have much to offer us in terms of insight into how the firefighter's mind functions under stress. Yet, we have been slow to integrate these disciplines into our profession, perhaps because we have focused our scientific efforts for so long on understanding the physics of how fires burn.

The 1978 "common denominators of fire behavior" booklet states that "each set of circumstances has the potential for creating a tragedy or near-miss fire. Often, human behavior is the determining factor." Thirty-two years later, that statement still rings true. While the importance of human behavior in wildland firefighting has long been recognized, for some reason we have been slow to deepen our understanding of it. We must continue to strive for an understanding of why firefighters' actions made sense to them at the time. What factors do they focus on, and why do those factors seem important? It could be that such an understanding might lead to a more definitive recognition of the common denominators of human behavior on tragedy fires. Ultimately, our goal is to have fewer and fewer of those to study.

References

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National Wildfire Coordinating Group [NWCG]. 2010. Incident Response Pocket Guide. Boise, ID: National Interagency Fire Center. 130 p.

Fire Management Today 2011 Photo Contest

Deadline for submission is 6 p.m. eastern time, Friday, December 2, 2011

Fire Management Today (FMT) invites you to submit your best fire-related images to be judged in our photo competition. Entries must be received by close of business at 6 p.m. eastern time on Friday, December 2, 2011.

Awards

Winning images will appear in a future issue of *FMT* and may be publicly displayed at the Forest Service's national office in Washington, DC.

Winners in each category will receive the following awards:

- 1st place: One 20- by 24-inch framed copy of your image.
- 2nd place: One 16- by 20-inch framed copy of your image.
- 3rd place: One 11- by 14-inch framed copy of your image.
- Honorable mention: One 8- by 10- inch framed copy of your image.

Categories

- Wildland fire
- Aerial resources
- Wildland-urban interface fire
- Prescribed fire
- Ground resources
- Miscellaneous (fire effects, fire weather, fire-dependent communities or species, etc.)

Rules

- The contest is open to everyone. You may submit an unlimited number of entries taken at any time, but you must submit each image with a separate release/application form. You may not enter images that were judged in previous *FMT* contests.
- You must have the authority to grant the Forest Service unlimited use of the image, and you must agree that the image will become public domain. Moreover, the image must not have been previously published in any publication.
- *FMT* accepts only digital images at the highest resolution using a setting with at least 3.2 mega pixels. Digital image files should be TIFFs or highest quality JPGs. Note: *FMT* will eliminate date-stamped images. Submitted images will not be returned to the contestant.
- You must indicate only one category per image. To ensure fair evaluation, *FMT* reserves the right to change the competition category for your image.
- You must provide a detailed caption for each image. For example: *A Sikorsky S-64 Skycrane delivers retardant on the 1996 Clark Peak Fire, Coronado National Forest, AZ.*
- You must submit with each digital image a completed and signed Release Statement and Photo Contest Application granting the Forest Service rights to use your image. See <http://www.fs.fed.us/fire/fmt/release.pdf>.

Disclaimer

- A panel of judges with photography and publishing experience will determine the winners. Their decision is final.
- Images depicting safety violations, as determined by the panel of judges, will be disqualified.
- Life or property cannot be jeopardized to obtain images.
- The Forest Service does not encourage or support deviation from firefighting responsibilities to capture images.
- Images will be eliminated from the competition if they are obtained by illegal or unauthorized access to restricted areas, show unsafe firefighting practices (unless that is their expressed purpose), or are of low technical quality (for example, have soft focus or camera movement).

To help ensure that all files are kept together, e-mail your completed release form/contest application and digital image file at the same time.

E-mail entries to:
fmtphoto@me.com

Postmark Deadline is 6 p.m., Friday, December 2, 2011

The Wildland Fire Decision Support System: Integrating Science, Technology, and Fire Management

Morgan Pence and Thomas Zimmerman

Federal agency policy requires documentation and analysis of all wildland fire response decisions. In the past, planning and decision documentation for fires were completed using multiple unconnected processes, yielding many limitations. In response, interagency fire management executives chartered the development of the Wildland Fire Decision Support System (WFDSS).

WFDSS is a Web-based system for comprehensive, risk-informed decisionmaking and implementation planning. WFDSS is linear, scalable, and responsive to changing fire situations, provides a documentation system that is applicable to all unplanned fires, and integrates the best available science into fire management in an efficient and practical manner. It provides access to a suite of weather analysis and fire behavior prediction tools that provide managers information on season-ending event timeframes, fire size probabilities, fire spread pathways and short-term arrival times, fire weather forecasts, and historical weather trends. Economic assessment tools describe values at risk, historical fire costs, and total fire cost estimates.

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Documenting Decisions and Tracking Analysis

Prior to WFDSS, fire managers used different decision and documentation processes depending on the driving management strategy and the estimated duration of an incident. Wildland fires managed with suppression objectives required a wildland fire situation analysis (WFSA) to be completed, while fires managed for resource benefits needed a wildland fire implementation plan (WFIP). Additionally, suppression incidents expected to be of long duration also required a long-term implementation plan (LTIP).

WFDSS is a Web-based system for comprehensive, risk-informed decisionmaking and implementation planning.

These processes had many limitations, including preparation of data, tool access, timeliness, and quality of the final product. Often, there was pressure to complete these processes while fire managers were busy with urgent fire management tasks. These processes were completed on paper or through desktop software and often did not document all critical information in an easily usable and viewable format. WFSAs were frequently prepared quickly, late at night, after an unintended outcome.

The quality of the final product varied and sometimes contained redundant decisions or recommended actions that had a low probability of success. Sometimes, unrealistic alternatives were created, analyzed, and then abandoned. There was often little input from specialists and resource managers. Standards and guidelines from agency land and resource management plans were not always well linked and documented. Incident size was sometimes poorly estimated and planning areas were incorrectly drawn, resulting in costly revisions. These limitations of past processes warranted change.

A Changing Fire Environment

The fire environment has changed over the past century. Dramatic shifts in the overall fire management situation, specfic strategies and management capability have occurred throughout the history of fire management (fig. 1). Fire management complexity continues to rise as a result of altered vegetative conditions and fuel complexes, combined with recent trends in seasonal weather and fire danger. Meanwhile, operational capacity has remained unchanged for years—although it saw a small increase after the fire season of 2000, when more resources were made available by national legislation. Since the middle of the last century, use of prescribed fire and fires managed for resource benefits has expanded, science and technology has improved steadily, and decision support has expanded rapidly. To match current and projected trends in fire complexity (in terms of its nature and our responses), all of these factors will bring about an increased reliance on decisionmaking, including development of a new decision support methodology to advance decision documentation and analysis.

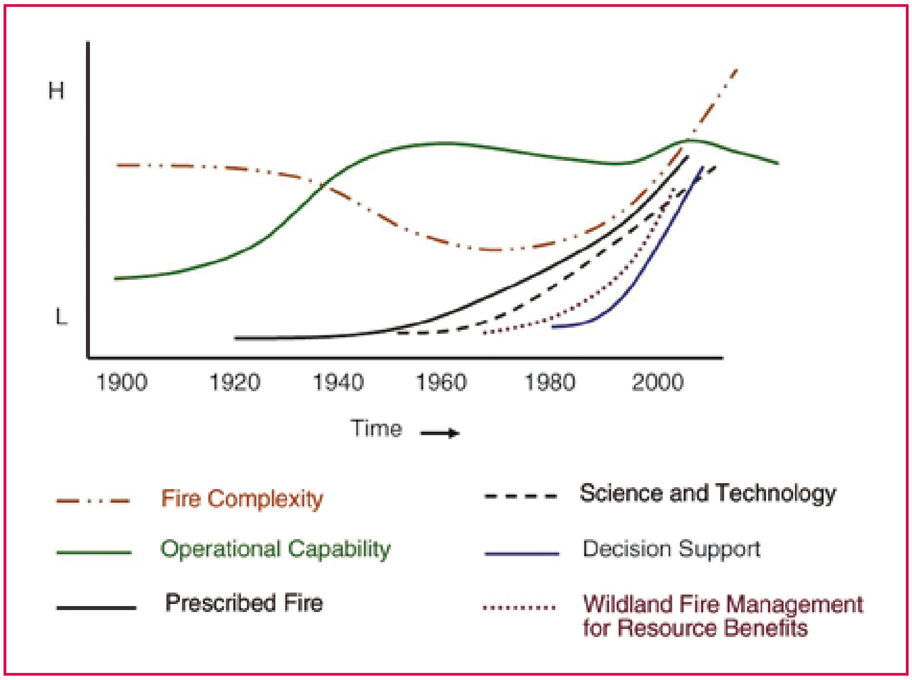

Figure 1—*The changing wildland fire management situation emphasizes the need for new decision support methodology.*

In response to increased wildland fire complexity, the need for standardization, and improved efficiency, the National Fire and Aviation Executive Board (NFAEB) chartered WFDSS in 2005. WFDSS supports and documents wildland fire decisions through a host of risk assessment and economic analysis tools. When existing strategies are not sufficient to address a fire situation, WFDSS allows for the creation of courses of action and implementation plans to address increasingly complex wildland fires. WFDSS replaces and consolidates the WFSA, WFIP, and LTIP processes within a single process that is intuitive and easy to use. Line officers, fire managers, and analysts can use WFDSS to plan, manage, and support decisionmaking on wildland fires.

What Makes WFDSS Different?

WFDSS is uniquely different from other decision systems that have been used in wildland fire management. The advantages of WFDSS are that it:

- Is a comprehensive, Web-based system useful for decisionmaking on all wildland fires;
- Does not require a comparison of multiple alternatives but does accommodate this if desired;
- Utilizes spatial displays as its foundation, reducing the need for large text inputs;
- Allows for incorporation of multiple unit objectives and requirements and provides space to create incident-specific objectives and requirements;
- Does not dictate a course of action but provides a framework and information for decisionmaking and process documentation;
- Allows fire managers and line officers to view the parameters of past and current incidents in an area in order to consider combined and adjacent effects;
- Provides immediate availability of products;
- Produces outputs from fire behavior and economic tools much more quickly than previously possible;
- Allows managers and line officers to use tool outputs to better communicate fire information to cooperators and non-fire individuals and agencies;
- Provides for risk-based decisionmaking while matching the process to the decisions; and
- Is linear, scalable, and customizable according to need.

WFDSS Attributes

Beyond meeting the documentation needs of fire managers and line officers, WFDSS has attributes that address the limitations of the previous decision documentation methods. These attributes include:

- Accessibility: WFDSS is a Web-based system and does not require users to install and update desktop programs or share paper copies. Users need only an Internet connection and login identification to access WFDSS. This provides for easy and quick access to the tools and information within the system.
- Consistency: WFDSS is consistent with accepted models of risk-informed decisionmaking.
- Flexibility: WFDSS matches different types of analyses with different kinds of risk characterizations and decisions. It makes risk characterization intuitive, logical, relevant, and understandable.
- Information assembly and consolidation: Data that already exist from different sites are consolidated to present concise information.
- Adaptability: WFDSS provides a decision framework that is linear, scalable, progressive, and responsive to changing fire complexity. As incidents progress in size and complexity, WFDSS provides decision and documentation support to match fire management needs. Specific analysis tools can be accessed to address changes in fire conditions.
- Geospatial capability: Geospatial displays in WFDSS reduce the amount of text needed by presenting the information spatially. Geospatial display of preloaded landscape layers allows for a quick situational analysis and displays of potential fire behavior, resource values, and management action points. These layers can be viewed at varying resolutions and multiple scales (fig.2).
- Safety and resource availability assessments: WFDSS provides information for the consideration of safety, risk, and the availability of resources as part of the decision process.

WFDSS allows for the creation of courses of action and implementation plans to address increasingly complex wildland fires.

WFDSS User Roles

Access to WFDSS is gained through user role assignments. Role assignments match individual responsibility and expertise to the job duty and tools in WFDSS needed to make decisions. User roles include viewer, dispatcher, author, geographic area editor, national editor, fire behavior specialist, rapid assessment of values-at-risk (RAVAR) analyst, and super analyst.

WFDSS Structure

The decision support structure in WFDSS is linear with the following organization: information, situation, objectives, course of action, validation, decision, periodic assessment, and reports. The function of each is as follows:

- The information section is used to obtain and review incident information, such as area jurisdiction, fire size, and fire location.
- The situation section is used to view maps, reference data layers, and applicable fire behavior and economic assessments (fig. 3).
- The objectives section displays individual land and fire management plan strategic objectives and management requirements; it also provides space to create incident-specific objectives and requirements.

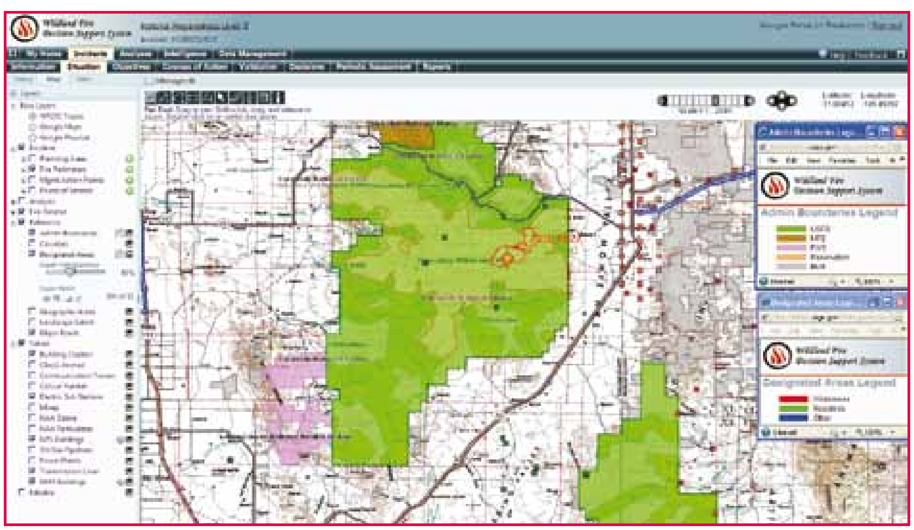

Figure 2—*The 2010 Horseshoe fire (Arizona) with a backdrop of administrative boundaries and designated areas, building clusters, Forest Service buildings, major roads, transmission lines and electric substations displayed in the WFDSS's situation map page. WFDSS's spatial displays can quickly convey such critical information.*

- Within the course-of-action section, users can define a specific course of action for an incident. These can range from following a predefined initial response to a detailed incident-specific description that includes management action points, resource commitments, and predicted costs.
- The validation section provides a review of the situation, objectives, and course of action parameters to ensure that the unit and incident objectives can be met. If they cannot be met, the validation section guides the development of a new course of action.
- The decision section allows the appropriate line officer to approve the decision and provide a rationale.
- The periodic assessment section provides a process for periodic review of the current decision, responses, and accomplishments in order to evaluate effectiveness, confirm accuracy, and continue or adjust associated planning activities.

Users can consolidate information into different documentation reports for viewing on screen or printing from the reports section. Reports can be generated for each of the WFDSS sections or for the entire WFDSS planning and analysis process.

Fire Behavior Prediction, Weather Analysis, and Economic Assessment

WFDSS provides access to a host of fire behavior prediction, weather analyses, and economic assessment tools to gain better situational awareness and fire potential. These tools aid in determining fire size probabilities, season-ending event timeframes, historical weather trends, fire spread pathways and short-term arrival times, fire behavior characteristics, fire weather/fire danger forecasts, information on values at risk, historical fire costs, and estimated total fire costs.

WFDSS includes the fire spread probability (FSPro), basic fire behavior and short-term and near-term fire behavior prediction tools. Fire size probabilities can be modeled with FSPro. FSPro calculates two-dimensional fire growth and maps the probability that fire will visit each point on a landscape of interest within a specified time, based on the current fire perimeter or ignition points and in the absence of suppression. FSPro uses current weather forecasts and historical climate data along with landscape and fuel characteristic layers to calculate these probabilities. Within the FSPro options, users can also view season-ending event timeframes and historical weather trends (fig.4).

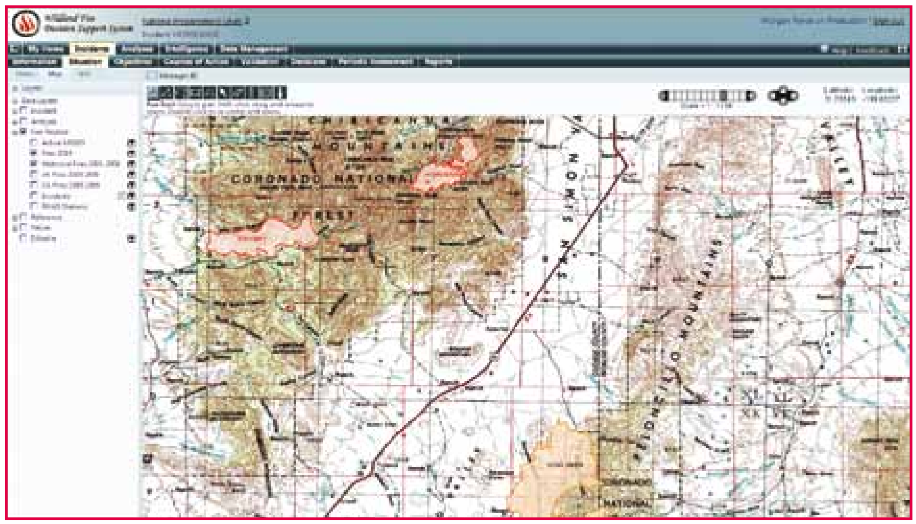

Figure 3—*To-date 2010 fires in red and historical fires (2001–2009) in orange displayed on WFDSS's situation map page.*

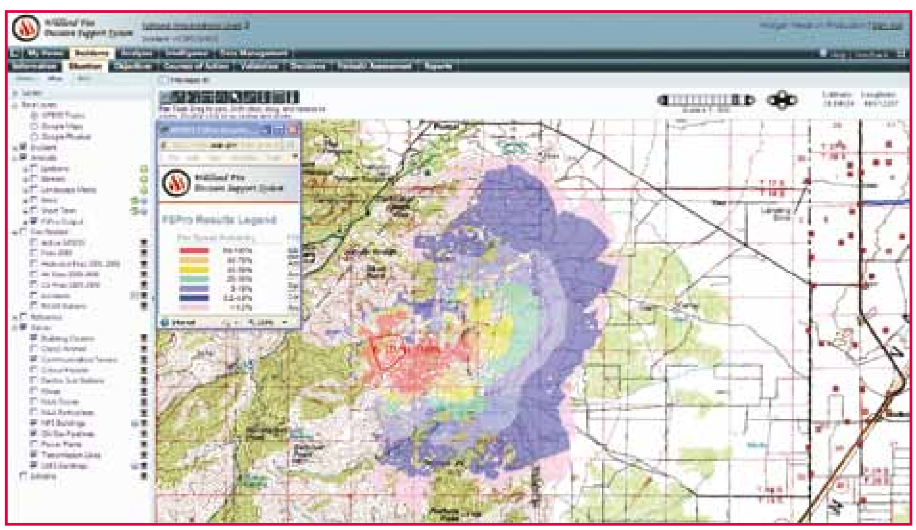

Figure 4—*Fire spread probability (FSPro) results displayed on the WFDSS situation map page. These results can easily be displayed and reviewed by fire managers and included as part of a decision document.*

Fire spread pathways and arrival times can be modeled in WFDSS using the short-term fire behavior tool. Outputs include the arrival time of a fire to reach a given area and the major pathways the fire will follow over a landscape given a consistent wind speed and direction. The basic fire behavior tool in WFDSS can be used to determine fire behavior characteristics such as flame length, rate of spread, and fireline intensity across an entire landscape for one moment in time and under specific weather conditions. The near-term tool uses hourly forecast weather data to produce sub-daily perimeter projections and fire behavior characteristics such as flame length and rate of spread.

In addition to these fire behavior prediction tools, fire weather and fire danger forecasts are readily available in WFDSS. To access the most current weather and fire danger forecasts, users click on a location of interest on a map, and the most up-to-date forecasts appear on screen. These fire behavior and fire weather/fire danger tools provide valuable information to fire managers and line officers to aid in strategic planning and formulating courses of action.

The economic assessment tools in WFDSS provide information on resource values at risk, historical fire costs, and estimated total fire costs. The Stratified Cost Index (SCI) tool calculates the expected costs of a large fire given its characteristics, based on past fire costs. Users can quickly view historical fire costs and include these values in their decision documentation.

Another available economic assessment tool is the RAVAR tool. RAVAR identifies primary resource values-at-risk on large incidents and is integrated with an FSPro model output to identify the likelihood of different resources being affected. RAVAR can aid in developing strategies by identifying and quantifying the significant resource values most likely to be at risk.

Additional Resources

In addition to the WFDSS production site (used for decision support and documentation for actual wildland fire events), there is also a separate WFDSS training site. The training site can be used by fire managers and line officers to practice using the system, become familiar with the decision documentation process, and use the analysis and assessment tools without disrupting or affecting actual incidents. To obtain a WFDSS user account, visit the WFDSS homepage <http://wfdss.usgs.gov>, the source for information on WFDSS training, related resources, frequently asked questions, and more. Many products are complete within WFDSS while others are still under development, and some will continue to evolve as modeling and display technology improve. WFDSS will be updated as improvements are made to integrate the best science and technology with fire management to assist effective decisionmaking. ■

Just Culture Part 2: Understanding Why Accidents Happen

Steve Holdsambeck

Recognized by James Reason more than 20 years ago as crucial to a safety culture, "Just Culture" is an intuitively compelling, ethical system of accountability. As wildland fire agencies transition to principle-based management, safety and reliability are especially vulnerable unless the organization is committed to learning from accidents and close calls and then exploiting this knowledge through an aggressive risk management system.

Safety Is Not an End State

A Just Culture, as Dr. Reason espoused, is a safety management system predicated on the sciences of human factors and risk management. These disciplines have dominated recent advancements in human performance-based safety management efforts such as high-reliability organizing, resilience engineering, and human performance improvement, to name a few. One commonality among these disciplines is the understanding that:

- Risk is everywhere.
- Risk is a byproduct of production.
- There is an inherent tension between the competing goals of safety, efficiency, and effectiveness.

Steve Holdsambeck is a fire operations safety officer for the Forest Service, Intermountain Region, in Ogden, UT. Much of the information in this article is taken from his work on the Accident Prevention Analysis Guide (USDA 2010). Holdsambeck has been advocating the adoption of a Just Culture in the Forest Service through lectures and writings since 2005.

The traditional strategy of a safety program has been to create conditions of operation that are free from danger. It has taught that safety can be achieved through principles of engineering, enforcement, and education. This view holds that accidents happen because employees unwittingly and invariably introduce unreliability into an otherwise safe system. The consequence of this paradigm is that accidents other than those attributed to nature must be an employee's *fault*. In other words, the workplace could be viewed as safe if only employees performed as intended.

> No problem can be solved from the same consciousness that created it.—Albert Einstein

This paradigm has itself generated unintentional outcomes, such as:

- Opportunities to learn from serious accidents have been compromised by the practically meaningless conclusion of "human error."
- Employees fear disclosing operational errors because these errors will be labeled as causal factors in any resulting accident, whether or not the error had anything to do with the outcome.
- So many rules have been generated to control employee behavior that, in aggregate, they have reduced an employee's ability to creatively react to novel situations.
- The cultural and organizational meaning of the word "safe" has come to mean an end-state of full compliance with rules and adherence to procedures and rules.

In 2006, the Chief of the Forest Service signed the Forest Service Foundational Doctrine (USDA 2005). Under this direction, safety and performance reliability are seen as proactively managed through alignment with principles of risk management. The doctrine asserts that safety is about managing risks and not about managing compliance with rules. The doctrine views *safety* as the active process of managing risks rather than trying to manage outcomes.

A concise definition of "safety" under the new doctrine is: "continuous creativity in response to ubiquitous risk." From this perspective, we see that our employees are expected to help create safe work environments in situations that are inherently unsafe. This paradigm challenges traditional approaches and is unsettling to many traditionally trained employees. Moreover, this understanding of the meaning of safety has profound implications for how managers should react to unintended outcomes. Most importantly, the doctrine emphasizes that there is never an end state in safe operations.

Acceptability of Risk

Under the doctrine, risk management replaces safety management. The practice of risk management involves identifying the various hazards associated with a task or a system, calculating or estimating hazard severity and likelihood, and then mitigating these to the level that is acceptable to administrators. In choosing a suppression strategy, for example, an administrator may determine he or she is only willing to accept a 1 in 10 chance of structure loss: any suppression strategy that has a less than 10 percent chance of structure loss is "acceptable" and, therefore, so are consequences of the strategy even if structures are ultimately lost.

With respect to human safety, however, we expect and require administrators to set extremely low levels of acceptable risk. The phrase: "as low as reasonably practicable" (ALARP) is common in the vocabulary of risk managers and defined as the level at which any additional mitigation required to achieve it would be so expensive as to make the task or the objective no longer worth pursuing. In theory, ALARP is the level of acceptable risk we establish for wildland firefighters, and it guides "no-go" decisions when risks exceed this threshold.

In practice, however, the risks faced by wildland firefighters are vague, situational, and statistically unquantifiable. Even the science of fire behavior forecasting is largely an art predicated on the further art of weather forecasting. Calculated probabilistic risk assessments are impossible in the wildland fire environment. Risk assessments, therefore, are typically an evaluation of relative subjective ratings, such as "extreme," "very high," "high," "moderate," and so forth.

Accidents Happen Because…

- **Universals:** the ever-present tensions between production and protection create
- **Conditions:** latent factors that collectively produce defensive weaknesses that
- **Cause:** permit the chance conjunctions of local triggers and active failures to breach all the barriers and safeguards.

—James Reason (2008)

Promoting the Dialogue

Just Culture enhances the quality of risk management decisions because it enhances the quality of dialogue between administrators and firefighters. Inevitably, firefighters see and interpret risks differently than administrators. Their training and experience gives them a different view of what presents a threat and what *feels* like a safe strategy. They also feel—quite literally—the consequences of excessive caution in the form of homes (not seen simply as structures) burning, fire lines lost, and days of hard labor apparently wasted, and feel the frustration in seeing small fires become dangerous due to a lack of aggressiveness, when aggression might have made the difference.

Consciously or not, firefighters conduct their own risk assessment and set their own ALARP threshold based on their experience, peer and cultural pressures, values, assumptions, and intuition. Lacking a basis for qualitative risk assessment, administrators need an open, honest, and unguarded dialogue with firefighters.

The Gap: Work as Imagined vs. Work as Done

Inevitably, there is *always* a difference—"the Gap"—between how firefighters in the field make sense of risks and sort out competing goals and how administrators imagine firefighters are making sense of risks and competing goals. The Gap is a fascinating and frustrating phenomenon to human factors and safety professionals. In spite of all well-crafted and explicitly mandatory risk mitigations, training, disciplinary action, incentives, and other attempts to manage performance, work simply doesn't happen the way it is prescribed. The reasons why even the most conscientious and professional among us depart from prescribed procedures is most aptly articulated by Nathanael & Marmaras (2008):

> In any field of practice, people do not just receive the top-down prescriptions and a definite plan for action. More often than not, they treat prescriptions as a constraint and an affordance space, devising their own original understanding of what, how, and why. The original understanding will be built through an interpretation of prescriptions, in a mute dialectic with their accumulated experience, motivational stance, peer accountability, but also depending on the particular circumstances of the moment.

The use of the term "affordance space" is particularly appropriate in the discussion of firefighter values. Through the lens of an individual's values, every prescription has an individual interpretation. Values, even more so than prescriptions, determine employees' affordance space for how they interpret and perceive risk and then manage trade-offs between effectiveness, efficiency, safety, and multivariate cultural and peer pressures.

Under routine operations, the Gap is unnoticed, but in the wake of an accident, it will suddenly appear. A quick review of almost any recent accident investigation report will show the report writers themselves were somewhat dumbfounded that firefighters could not have foreseen how their non-compliance with rules and procedures (that is, what administrators imagined firefighters should be doing in that situation) put themselves at grave risk. In a traditional compliance-based culture, there are powerful incentives to obfuscate, conceal, ignore, and deny that the Gap exists. Even when subtly stated, those fire ground commanders at "the sharp end" of an operation—those whose interpretation of risks and competing goals are most likely to differ from the administrators' interpretations—are most likely to be blamed for non-compliance, and that non-compliance is blamed as the cause of any resulting accident.

In a Just Culture, management accepts that the Gap will always exist and cherishes glimpses across it. Importantly, addressing the Gap with additional prescriptions may *reduce critical safety margins* enabled by creativity and flexibility. If operational areas within the Gap are found to be unacceptable to administrators, it is because the values of administrators and firefighters are out of alignment, and a realignment of values should be a focus of the agency's efforts.

Acknowledging and respecting the Gap—not simply trying to close it—is itself a challenge. As Sydney Dekker (2009) said: "The ultimate dilemma of a Just Culture is that management needs to know what is actually going on—but management cannot accept everything that is going on."

> The future seems implausible before an accident...*But after the accident, the past seems incredible.*—David Woods and Richard Cook

Just Culture can make this tension workable. To illustrate this, consider the following examples:

- The rule: *Wear a hardhat on the fireline* is almost universally accepted throughout all layers of the fire organization. It has a very low cost-to-benefit ratio and a reasonable return on safety. The values concerning risk tolerance between firefighters and administrators are in good alignment when it comes to wearing a hardhat. The Gap on this issue is very small.
- The rule: *Wear sturdy leather gloves on the fireline* is not universally accepted. Gloves can interfere with precision handwork (writing, adjusting radio knobs, etc.) and, at times, gloves can become very hot, sweat-soaked, and uncomfortable, discouraging their use. Most importantly, however, the firefighter knows he or she can put gloves on when needed to mitigate risks and take them off when the risk is not present. Unlike a hardhat, it is extremely unlikely a firefighter will ever be exposed to a hazard when gloves are needed but there is not enough time to put them on—providing that the gloves are immediately available.

From the view of many firefighters, taking one's gloves off when they are *not needed* (subjectively interpreted) is clearly an acceptable risk. The Gap between how an administrator presumes work is being done (all firefighters are wearing gloves at all times) and the reality (firefighters wear gloves when necessary) may be very large in some work situations. Under a Just Culture, administrators and firefighters can **trust** each other enough to discuss and debate the validity of this rule and align their values as to the reasonableness of the hazards and allowable risk. (For an example of an accident assessment that emphasizes employee empowerment in making decisions, see the Accident Prevention Analysis report for the Chalk Fire, available at <http://www.wildfirelessons.net/documents/Chalk_Fire_1109_Amendment.pdf>.

Decriminalizing the Gap

As previously mentioned: the more ambiguous the environment, the more humans tend to rely on intuition or that "gut feel" to assess the severity of a threat. Commonly, one hears even seasoned firefighters refer to how they *feel* about a potential course of action—deferring to intuition—when faced with a choice between equally compelling alternatives. For example, a firefighter might think: "I feel this is a good location for a lookout" or *"I feel the escape route is inadequate"* or ask: *"How do you feel about that dip site?"* This way of making decisions is acknowledged and accepted in certain situations: our national chainsaw certification program trains advanced hazard tree fallers to make "go/no-go" decisions based on their individual and personal *comfort level*.

Everyone's tolerance to risk is different to the extent that their values are different. The greatest disparity in the *acceptability of risk* in the wildland fire environment could be expected between an office-trained administrator and a highly experienced, battle-hardened firefighter. A Just Culture recognizes this as a human factor, not an error or a casual factor.

Decriminalizing the Gap is at the heart of a Just Culture. Indeed, the essential contribution of a Just Culture to risk management is that it insulates the dialogue between firefighters and administrators from retributive justice. It provides safe room for discussing the values that define the limits of acceptable risk. It is through this protected dialogue that the values of administrators and the values of employees become open to reason, analysis, dialogue, and alignment.

Analyzing Why Accidents Happen

Accidents and close calls should be viewed as tangible evidence that we (as an agency or culture) may not understand the risks we ask our employees to face and probably don't understand how our employees are managing the necessary tradeoffs between safety, production, and efficiency in accomplishing a mission. What is needed to promote this understanding is awareness, not pre-judgement. The beginning of understanding begins in challenging the belief that our "truth" is entirely objective. In fact, we construct the cause of an accident from selective hindsight and assign the obtuse term "root cause" according to how deep the investigator chooses to dig.

One of the products of a Just Culture is an honest understanding of why accidents happen. This understanding is based on a frank awareness of the human factors involved (especially the inherent conflict among safety, efficiency, and effectiveness) and the highly variable risks associated with the wildland environment and the role of chance. Under a Just Culture as under doctrine, safety is risk management and risk management is about decreasing the likelihood and/or the severity of an accident, not eliminating its possibility.

Addressing the Human Factor

There is another point to be made about safety: to be just, we must factor human nature into how we design safe systems and manage employee performance. To varying degrees, all humans are hardwired to tolerate (and even enjoy) some level of risk. We all take unnecessary risks for a multitude of psychological reasons and rationalized benefits, and some of us have a comparatively high tolerance for risk and actively seek out situations for the sake of risk alone. We hunt and fish and backpack in wilderness; we ride motorcycles, snowmobiles, and ATVs; we drive on icy roads to ski areas so that we can ski or snowboard down black diamond-rated slopes; we hang-glide off cliffs, jump out of airplanes, and ride rollercoasters. The iconic Paul Gleason—who arguably has done more for firefighter safety than anyone in the history of wildland firefighting—was an avid rock climber, and he had the scars, broken bones, and stories of near-death experiences to show for it. The list of unnecessary risks we willingly expose ourselves to (and frequently teach our children to enjoy with us) makes it clear there is something much stronger than the rationality of safety and security that drives human behavior.

All of us, both on and off the job, will intentionally take or accept unnecessary risks. This is not the same as recklessness. Sometimes, good and well-intentioned employees accept unnecessary risks because they sincerely believe it is in the best interest of the mission—for example, driving fast to get to a fire—and sometimes they take on these risks for the fun of it—for example, driving fast because it's fun to drive fast. Sometimes, good and well-intentioned employees accept unnecessary risks because the situation enables them to rationalize both the fun and the best interest of the mission together—for example, driving fast because it is fun **and** we are en-route to a fire. In the real world, such "errors in judgement" are complex, nuanced, situational, and ultimately only "settled" through the biases of the person charged with deciding how the "errors" should be disciplined (Dekker 2007).

Through our traditional paradigm of safety (viewing safety as an end-state), the notion of *intentional* unnecessary risk-taking is depreciated and goes unstated unless it crosses the arbitrary bounds of gross or criminal recklessness. This is unfortunate because intentional risk-taking, even for sake of risk itself, is not unusual or anomalous, and it certainly should not be unexpected behavior.

Intentionally accepting unnecessary risks is a salient human factor. Furthermore, the more times that unnecessary risk-taking happens without adverse consequences, the less "risky" the behavior actually seems, and a new norm becomes established.

Just Culture, Fairness, and Accountability

Principles of Just Culture promote a workplace in which employees at all levels are held *fairly* to account for their participation and commitment to the organization's safety culture.

Accountability is fair or "just" because workers "at the sharp end" of an operation are uniquely recognized to be inheritors of the production incentives, tools, training, procedures, and even the safety vs. production *values* of the workplace. Managers, in contrast, are expressly held to account for management of these artifacts, including the safety vs. production values of the workplace.

A Just Culture asserts that **all** human factors must be acknowledged and should be open for fair, honest analysis and criticism. If our employees involved in an accident feel that intentional unnecessary risk-taking was acceptable, it may be much more important (especially to the organization, safety managers, administrators, and system designers) to know **why** they felt it was acceptable than it is to try to discipline them for that feeling. This is the higher value of the dialogue enabled by a Just Culture: often we find that risks deemed unnecessary by management seemed reasonable to the employee. Again, as Sydney Dekker (2009) said: "The ultimate dilemma of a Just Culture is that management needs to know what is actually going on—but management cannot accept everything that is going on."

Moving Forward

Principle-based management (the fire suppression doctrine) introduced by the Forest Service in 2005 is a major advancement with respect to the safety of wildland firefighters and the resilience of the firefighting organization. This management philosophy seeks to manage safety through *risk-based decisionmaking* while departing from the emphasis on *compliance with rules*. The advantage of risk-based decisionmaking is that it can address actual, real-time risks while rule-based decisionmaking addresses historical and imagined risks that may not be relevant to a given situation. While rule-based decisionmaking is highly effective in engineered environments (such as a factory setting), rule-based decisionmaking can seriously degrade the mindfulness needed to recognize emerging risks in environments where risks are complex and cumulative or cannot be engineered out of the workplace (such as the wildland fire environment).

This is not to say that risk-based decisionmaking is perfect. The vulnerability of risk-based decisionmaking is that employees may not interpret risks accurately and may not share the administrator's level of risk tolerance. The safety problem under current doctrine thus becomes: *How does leadership manage the workplace to ensure that the systems support firefighters in accurately perceiving risk, accurately interpreting risk, and then making decisions that are aligned with the principles and values of the agency?* This is the symbiosis between doctrine and Just Culture. In a Just Culture, management purposefully learns from employees how work actually gets done and then enhances performance-shaping factors without impeding future learning. Under a Just Culture, management is able to balance the inherent but fundamental tension between needing to know what is going on and **not** being able to accept *everything* that is going on.

In a mature Just Culture, information is valued as the lifeblood of safety. In it, all employees must disclose unsafe conditions and individual mistakes and share stories of how they manage the tradeoffs between safety, efficiency, and effectiveness regardless of outcomes because of the certain, fair, and just distribution of rewards for this participation within a culture of safety.

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Implementing Management Systems for Aviation Safety

Ron G. Hanks

The Pulaski Conference in June 2005 launched the doctrinal approach to fire and aviation management in the Forest Service. Since that time, much has occurred behind the scenes to effect change in our culture, in our operational decisionmaking, and in the way we view risk management.

It is expected that the revised Forest Service Manual for fire management (FSM 5100) will be released in 2011, with revised aviation manuals not far behind. Policy changes in the revision will codify the doctrinal approach, which will help to soften the criticism that doctrine previously has been presented in a "flavor of the month" fashion. Little known by most of the agency, however, is that one goal of doctrine is to improve leaders' decisionmaking ability and, consequently, to improve the safety of Federal employees and contractors in the wildland fire environment.

With additional doctrinal decisionspace comes increased exposure to risk. Risk management is on center stage as an example of the shift in culture for fire and aviation managers. This process is one function of the four pillars embedded in the modern approach to accident prevention called the Safety Management System (SMS).

Long recognized in the international aviation community, SMS is gradually finding its way into commercial aviation operations in America. Commercial aviation contracts account for approximately 90 percent of the flight hours in the Forest Service annually. It is crucial that we include our contractors in a joint venture toward a world-class accident prevention process. The pie chart in figure 1 depicts the distribution of contractor fatalities during the past 10 years and emphasizes the high risk associated with aviation operations, in which 80 percent of all fire-related contractor fatalities in the Forest Service occurred.

Risk management is on center stage as an example of the shift in culture for fire and aviation managers.

Why SMS?

SMS has tremendous potential for establishing uniform safety standards and reducing risk across interagency firefighting efforts. Adoption of SMS is significantly more complex than simply adding a few new rules and providing additional training.

SMS is typically characterized as a structure of systems to identify, describe, communicate, track, control, and eliminate risks. The International Civil Aviation Organization (ICAO), a sub-organization of the United Nations,

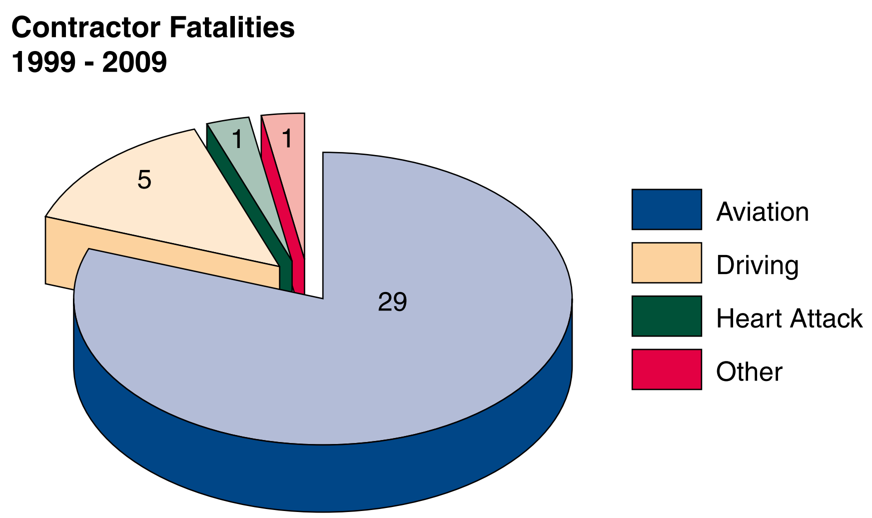

Figure 1—*Distribution of fatalities in Forest Service firefighting operations. Source: 2010 Forest Service congressional report for Public Law 11, the Omnibus Public Land Management Act of 2009.*

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created the model for SMS in its own aviation safety programs. The formal definition of SMS is "a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies, and procedures" (ICAO 2009).

In hindsight, we can see the shortcomings of the old aviation safety approach, which followed a "Fly-Crash-Fix-Fly" model. The early 1960s saw structural failures (lost tail surfaces) in B-25s, and these aircraft were subsequently banned from retardant applications. Again in the 1980s, a series of in-flight wing failures were experienced in Fairchild C-119 airtankers, and their use was also then halted. The third group of failures occurred between 1996 and 2002, resulting in removal of C-130 and PB4Y airtankers from the contracted airtanker fleet.

Those events raised an awareness of a cultural component of risk assessment that was not previously understood. It became obvious that a pattern of structural failures was occurring, and resulting losses were deemed acceptable by the aviation culture of that time. The National Transportation Safety Board investigators recommended greater oversight of the airworthiness of airtankers and a change in the existing management culture. As a result, the Forest Service mandated continuous airworthiness inspections to detect and mitigate structural problems before they manifested themselves as component failures. This was the first step in the movement toward SMS in the Forest Service aviation program.

SMS is based on a proactive approach to safety rather than a reactive one. The proactive approach engages practitioners in collecting data for analysis of operations, identifying risks, and determining the best methods of mitigating them before shortcomings result in an accident. It is important to note here that this approach locates risk identification and mitigation in the field with the operator. This is also a change from prior practices, in which responsibility for safety resided primarily with the safety officer, and a committee reviewed incident information only after an unsafe event occurred. Operators and service providers must now accept equal responsibility for safety management, as reflected in the airtanker industry's current maintenance and airworthiness practices.

It is crucial that we include our contractors in a joint venture toward a world-class accident prevention process.

The development of an effective safety culture is predicated on a relationship of trust between the organization and its employees, the employee and the regulator, and the regulator and the service provider. The Forest Service relationships involve its employees, the Federal Aviation Administration (FAA; the regulator), and Forest Service aircraft contractors (the service providers), which operate on more than 300 contracts in any given year. In some cases, levels of trust already exist, but more often, it will take time to establish a foundation for this relationship.

Tools that promote growth in these relationships are found in the areas of policy, safety assurance, safety promotion, and risk management. These pillars of SMS are designed to encourage communications, reporting, and feedback on the system's inputs and outputs and foster continuous improvement. New data-gathering processes are being developed for fire and aviation management to provide safety managers with necessary information for analysis. Revised policies allow more employee discretion (doctrinal) in working creatively with the contractor to get the job done efficiently and safely. To encourage these processes, all national aviation contracts now require that the service provider maintain an SMS program within the company and demonstrate SMS performance to the contracting officer during the competitive bid process.

Implementing SMS

Forest Service regional aviation safety managers (RASMs) attended their first SMS training in 2005 and have been gradually and actively developing SMS processes since that meeting. The first steps taken were to focus efforts on risk management.

The accident prevention model for risk management requires a seven-step evaluation process:

1. Identify the operational systems (e.g., dispatch, pilot training, and aircraft maintenance).
2. Describe hazards and their effects.

3. Assess the level of risk in each operational system by evaluating the probability and severity of the hazard occurring in the operation.
4. Develop mitigation measures to reduce risk to acceptable levels.
5. Implement an action plan to engage the mitigations.
6. Monitor and evaluate the effectiveness of the action plan for mitigation.
7. Revise the mitigations as appropriate and repeat the evaluation process.

Following this process, once the hazard is identified, the next step of assessing probability and severity of an event is crucial in prioritizing an action plan.

Matrices (tables 1a and 1b) present classifications used both in the Forest Service and the contracting industry for risk probability and severity assessment. Similar matrices are found in the draft SMS Guide. Other risk matrices (e.g., in the Aviation Risk Management Workbook [USDA Forest Service 2010] and Interagency Helicopter Operations Guide [NIFC 2009]) are also in use, but all have the same intent and purpose in the risk management process.

In 2006, the Forest Service's Aviation Safety Center began the process of producing risk assessments for each aviation mission and implementing mitigations in the field. By 2008, the Aviation Risk Management Workbook (ARMW) was published, including comprehensive risk assessments and mitigations for firefighting missions involving heavy and single-engine air tankers, helicopters, supervisory aircraft, and infrared aerial surveillance aircraft. The 2010 edition

Table 1a—*Risk Assessment Matrix.*

Probability	Severity				
	A Catastrophic	B Critical	C Major	D Minor	E Negligible
5 Frequent	5A	5B	5C	5D	5E
4 Occasional	4A	4B	4C	4D	4E
3 Remote	3A	3B	3C	3D	3E
2 Improbable	2A	2B	2C	2D	2E
1 Extremely Improbable	1A	1B	1C	1D	1E

Table 1b—*Risk Tolerability Decision Matrix.*

Color Zone	Score	Decision Requirements
Red	5A, 5B, 5C, 4A, 4B	5A–5C rating: unacceptable under the existing circumstances. The action or event must not be undertaken. Imperative that risk be reduced if action or event is to proceed. 4A–4B ratings: the action may only proceed with approval of a line officer or Washington Office approval. Operations in an incident command system (ICS) organization must be approved by the incident commander (IC) or the responsible line officer.
Yellow	5D, 5E, 4C, 3B, 3A, 2A	The action or event may proceed with the approval of the region aviation officer or fire director. This may be a standing approval if associated with a previous project aviation safety plan. Operations in an ICS organization must be approved by the IC.
Green	4D, 4E, 3C, 3D, 3E, 2B, 2C, 1A, 1B	The action or event may proceed either with the approval of local management or if there is a standing approved project aviation safety plan containing existing controls for this action or event.
Blue	2D, 2E, 1C, 1D, 1E	The action or event is always acceptable.

of the ARMW also includes forest health management assessments for aerial application, aerial photography, and aerial survey and sketch mapping, as well as a new section for Forest Service working capital fund aircraft maintenance.

In 2008, we also redrafted the old aviation safety plan and incorporated it within the new SMS Guide, which is now formatted to follow international standards. Concurrently, the Forest Service aviation management plan was redrafted to incorporate SMS principles in order to emphasize risk assessment and quality assurance (QA) roles in operations. The current draft version of the SMS Guide can be found online at the National Aviation Safety Center Web site, <http://www.fs.fed.us/fire/av_safety/index.html>, under "Policy."

Revision of FSM 5720 moved a significant portion of policy to the SMS Guide; both of these publications are being distributed to the fire and aviation community for comment, with intent to publish the final document in 2011.

The latest area of attention for SMS growth is in the area of safety assurance. An audit by the Office of the Inspector General (OIG) in 2008–2009 revealed serious shortfalls in the Forest Service's ability to provide in-depth inspection, evaluation, and oversight of its contractors. Following several fatal aircraft accidents between 2002 and 2008, the combination of events and the audit report sparked the movement to organize a QA group within the aviation unit at the National Interagency Fire Center. As of this writing, the aviation program is recruiting personnel for 11 additional positions for QA nationally. Regional aviation officers and RASMs attended the first QA workshop in Boise, ID, in March 2010, and a new QA program quality plan is under development to guide the agency effort.

The focus of the QA program in 2010 is to more effectively identify, mitigate, and track deviations from agency standards. Each new project, mission, airplane, and process must be effectively assessed for risk and monitored for QA. Managers have access to data along the way to make decisions based on best practices established by industry standards and to achieve acceptable levels of risk. This "quality assurance cycle" for SMS is depicted in figure 2 below. While each process generates data for the next, interactivity also improves the amount and timeliness of data that can be made available to upper management for critical program decisionmaking.

Coping With Change

Change management will move the SMS into future Forest Service operations and organizations. As mentioned earlier, the transition to SMS takes time, perseverance, funding, and oversight. Leadership must assume the responsibility for codifying SMS processes and assuring that goals are achieved. The return on that investment will be a safer working environment.

One significant challenge for SMS implementation will be certification of the process under International Standard for Business Aircraft Operations (IS-BAO) standards. IS-BAO certification was developed to promote standardization and assist operators in establishing high-quality flight departments using best practices for business aircraft operations worldwide.

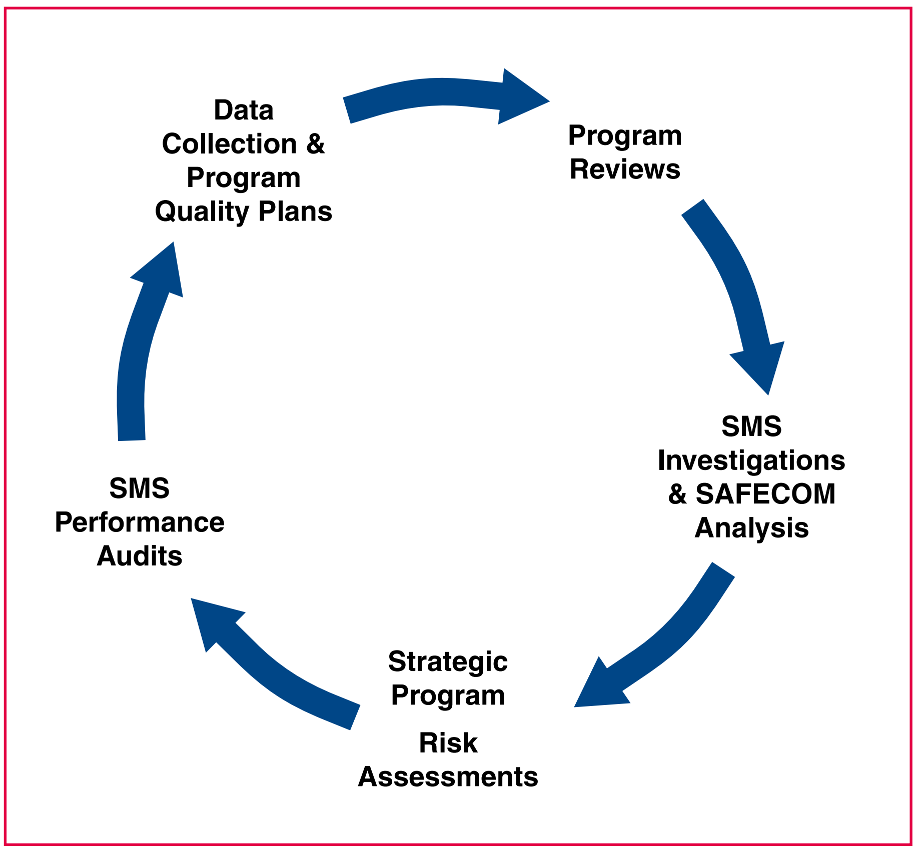

Figure 2—*Quality Assurance Cycle.*

IS-BAO certification is accomplished in three stages. The first stage involves certification of all of the basic SMS elements for Forest Service in-house fleet operations and creation of an action plan for achieving full compliance. Stage 2 certification requires an external audit to assure full implementation of the SMS standards internally and demonstrated progress toward adoption by our contractors. The third stage of certification, the "Gold Standard" certification, requires full SMS compliance throughout all aviation operations conducted by the Forest Service and our contractors.

IS-BAO certification indicates the final achievement of a "world-class" aviation safety standard. The Forest Service is already recognized on the global stage as a leading fire and aviation program, one that many countries wish to emulate. The challenge for aviation management now is in maintaining the drive to put all of the pieces together and incorporate the best of SMS into our everyday practices.

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What's the Difference Between a Facilitated Learning Analysis and an Accident Prevention Analysis?

Mike Apicello

Based on the experience of the Little Venus Fire shelter deployment review and other local efforts to implement a peer-review process, the Forest Service's Fire Operations Risk Management Council formalized two accident response guides designed to enhance organizational learning.

In 2007, the Risk Management Council produced the first iteration of the Facilitated Learning Analysis Implementation Guide and the Accident Prevention Analysis Implementation Guide. Both the FLA and the APA process strive to capture and share the learning value from accidents, including close calls and near misses.

The FLA process is intended to be a more basic analysis focused on local-level learning. The APA is deemed necessary for more complex events and serious accidents. The FLA has proven to be an effective tool for focusing on learning rather than on blaming. The APA tool takes this learning process and philosophy one step farther.

Each year, the Forest Service's Risk Management Council revises and updates both of these guides—based on hands-on implementation experiences.

While the FLA dissects an event and demonstrates to employees—through their own words—both what they should learn from the event and how they could similarly learn from subsequent events, the APA process identifies the cultural and organizational processes that enabled a more serious accident to occur. Thus, the APA process is designed to improve and promote growth in organizational safety and culture (as well as discussing any latent factors and conditions that—if not addressed—could contribute to subsequent accidents). Both the FLA and the APA guides are used to identify organizational safety areas, risks, or universal hazards that need to be identified and corrected.

How Accurate Is Your Kestrel®?

Gary L. White

Since the late 1950s, when the belt weather kit was first being developed (USDA Forest Service 1959), firefighters have been using the sling psychrometers from the kits to measure relative humidity on the fire line. Because humidity has such a great effect on fire behavior, knowing the relative humidity and how it is changing over time is a critical piece of information for any wildland firefighter. With the advent of 21st century technology, the sling psychrometer is gradually being replaced by digital hand-held weather meters, such as the Kestrel®.

Several years ago, while teaching at a wildland fire investigation training program, I heard from several students and a fellow instructor that their Kestrel® hand-held weather instruments were giving consistently low relative humidity (RH) readings. The instructor told me that any time he got a RH reading on his Kestrel® that was below 25 percent, he simply added 6 or 7 percent to get the "correct" reading. That practice struck me as inconsistent with good scientific data collection, so I thought

> For suppression and prescribed fire operations, accurate RH information can be critical.

I should test the accuracy of the Kestrel® myself.

Over the rest of that spring and summer, whenever I had the opportunity and the weather conditions were right, I'd check my brand new Kestrel® 3000 against my trusted (circa 1980) fire-belt weather kit sling psychrometer. Sure enough, when the sling psychrometer reading was 22 percent RH, the Kestrel® would show 16 or 17 percent RH. I checked the instructions that came with the Kestrel® for clarification: they said that the error rate for the RH sensor was ± 3 percent between 5 and 95 percent RH, so the Kestrel® readings should not be off more than 3 percent of the actual RH. Mine consistently gave an RH of 5 to 6 percent below my sling psychrometer. I also was hearing more reports of "Kestrel® errors": a prescribed fire manager in the Southwest refused to use the Kestrel® for weather observations because it consistently pushed him out of prescription conditions, and a fire behavior analyst in the Pacific Northwest refused to use the Kestrel® because it always read lower than his sling psychrometer. My initial reaction was the same as everyone else: the Kestrel®'s readings must be wrong. What could be causing this error? Was it a problem inherent to the Kestrel® RH sensor, was it a calibration problem, or were we, the users, doing something incorrectly?

My first thought was that, if this was simply random error in the

The Kestrel hand-held weather instrument (left) and a standard sling psychrometer (right).

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The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement of any product or service by the U.S. Department of Agriculture.

Kestrel® sensor, it should be just that: random. If this was the case, sometimes the Kestrel® readings should be above the sling psychrometer and sometimes below; but the readings I and other users were getting were consistently below those of the sling psychrometer. That experience seemed to argue against random error.

In 2000, the Forest Service Missoula Technology and Development Center (MTDC) conducted an evaluation of eight different hand-held weather instruments (Lemon and Mangan 2000). One of the instruments tested was the Kestrel® 3000. Although the Kestrel® gave the most accurate RH readings of any of the hand-held hygrometers in the evaluation, the Kestrel®'s readings were consistently 4 percent lower than the established standard. In fact, the summary table in MTDC paper shows that all of the hygrometers tested gave RH readings lower than the "standard." What "standard" did the MTDC authors use for comparison to the hand-held instruments? It was a sling psychrometer from a belt weather kit.

I called the manufacturers of the Kestrel®, Nielsen-Kellerman Company, and began a dialog with them that stretched over several months. When I first described the problem that we were experiencing, the Kestrel® representatives were polite but firm; their instruments, when properly calibrated, were accurate within the specifications outlined in their literature. This, of course, raised the next question: Was my Kestrel® correctly calibrated? My instrument was less than a year old, but I sent it back to Nielsen-Kellerman and they rechecked the calibration. The tested accuracy was ±0.4 percent, or less at the two reference RHs, well within the published specifications for the instrument.

Then I took the next step. I did an Internet search for scientific instrument testing and calibration labs. These are the type of labs that calibrate instruments for other government, industrial, and forensics laboratories. All of their work is certified to the highest engineering and scientific standards. I selected one and sent them my Kestrel®. I requested that they check the accuracy of the Kestrel® at three different RHs: 35, 25, and 15 percent.

> Could the sling psychrometer that we all have been using for so many years be inaccurate?

Within a week, I had the answer. The Kestrel® gave exactly the same RH readings as the sophisticated laboratory test equipment at the three test points.

Now comes the hard part. If the Kestrel® readings are correct, then the error must be in the sling psychrometer readings. Could the sling psychrometer that we all have been using for so many years be inaccurate by that much? Yes, I believe that it can, and here's why.

First, most of the RH observations taken on the fire-line are made with a sling psychrometer from a fire-belt weather kit with 5-inch thermometers. The best information I can get from distributors is that the accuracy for those thermometers is, at the very best, ±1 °F (±0.55 °C). If the wet bulb depression is off by 1 °F, that could easily change the RH reading by 3 or 4 percent. For example, given a dry bulb temperature of 75 °F (23.8 °C) and a wet bulb temperature of 53 °F (11.6 °C), the RH is 21 percent at 1,900 to 3,600 feet (580 to 1,100 m) elevation, according to the U.S. Department of Commerce reference tables. However, if the thermometer is high by 1 °F, then the RH reading would rise to 24 percent, a potentially significant difference.

Second, most of the "operator induced errors" lead to higher, not lower, wet bulb temperatures—or, in other words, less of a wet bulb temperature depression. Examples of these "operator errors" are: (1) not slinging the thermometers long enough to get complete wet bulb depression, (2) reading the wet bulb temperature after it has already started to recover, (3) using dirty water, and (4) having a dirty wick, which slows evaporation and results in higher wet bulb temperatures. All of these errors can cause sling psychrometer readings that result in erroneous values higher than the actual RH.

Finally, there can be errors in reading the tables or using the incorrect table for a given elevation; an error eliminated by the direct digital reading from the Kestrel®.

So why, given all the potential for error with the sling psychrometers, do we believe their results before we believe the Kestrel®? I think it is because the sling psychrometer is the "technology" that we know. It was the best and, in most cases, the only information we once had, so we all assumed that it was correct and had no "error rate." Out in the woods, we think we know what 25 percent RH "feels like," and when the Kestrel® indicates that the RH is actually 19 percent, our response is “No, it can’t be that dry!” The problem is, I believe, that the actual RH has been 19 percent all along; we just believed it was 25 percent because that was the reading we got from our sling psychrometers.

Another complicating factor, now, is that we are using a mixture of technologies: sling psychrometers of varying accuracy, hygrothermographs, hand-held instruments (e.g., Kestrel®s and others), and remote automated weather station (RAWS) sensor readings. All of these various instrument have differing degrees of accuracy, which may result in conflicting readings.

So why is this of any great importance? For me, as a fire investigator, I can eliminate or include certain categories of fire causes within fairly specific RH ranges. That’s important, but it’s not life-threatening. For suppression and prescribed fire operations, however, accurate RH information can be critical. Inaccurate information can have potentially tragic consequences in terms of escaped fires, resource damage, or loss of life and property.

Finally, the level of confusion in the field regarding the accuracy of the Kestrel® RH readings needs to be addressed. A definitive test to establish the accuracy of the Kestrel® (because of its increasingly universal usage) versus that of the sling psychrometer should be undertaken. It would be a major step toward reducing confusion and dispelling misinformation.

Much of the information presented here is anecdotal but, I believe, useful. Research with a sample size of one can hardly be called compelling scientific evidence, but it has convinced me that, given a choice between RH observations from a calibrated Kestrel® and a sling psychrometer from a belt weather kit, I’m putting my trust in the Kestrel®.

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USDA Forest Service. 1959. Belt Weather Kit. Fire Control Notes 20(4): 122–123. ■

Success Stories Wanted!

We’d like to know how your work has been going! Provide us with your success stories within the State fire program or from your individual fire department. Let us know how the State Fire Assistance (SFA), Volunteer Fire Assistance (VFA), the Federal Excess Personal Property (FEPP) program, or the Firefighter Property (FFP) program has benefited your agency. Feature articles should be up to about 2,000 words in length; short items of up to 200 words.

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A Synthesis on Crown Fires in Conifer Forests is Underway

Martin E. Alexander

The Joint Fire Science Program (JFSP) has elected to support a project aimed at synthesizing the currently available information on the characteristics and prediction of crown fire behavior in conifer forests (Alexander and others 2010). This would include such facets of crown fire behavior as the onset of crowning and the type of crown fire (passive, active, independent) and the associated spread rate and fireline intensity in relation to the wildland fire environment (i.e., fuels, weather, and topography).

While the focus is on North American forests, the synthesis is intended to be global in nature and is intended for multiple audiences ranging from the general public to college students, fire and land managers, university professors, and other researchers.

In addition to summarizing the existing scientific and technical literature on the subject, project members are also actively seeking assistance from individuals in the form of field observations of crown fires and related experiences as well as still pictures and video footage.

We are interested in hearing from you, the wildland fire community, as to your opinions on the subject of crown fires and any specific questions, research needs, or knowledge gaps that you would like to see addressed or discussed in this crown fire synthesis project. Feel free to contact any project team member.

Dr. Marty Alexander is an adjunct professor of wildland fire science and management in the Department of Renewable Resources and Alberta School of Forest Science and Management at the University of Alberta in Edmonton, Alberta, Canada.

Fayette Lake Fire burning in lodgepole pine at about 9,000 feet (3,000 m) elevation near the Continental Divide on the Jim Bridger Wilderness, Bridger-Teton National Forest, WY. Photo: Richard Claypole, Forest Service, Klamath National Forest, Happy Camp Ranger District, CA, 1988.

To learn more about JFSP Project 09-S-03-1 and ensuing developments, visit the crown fire synthesis project Web site at <http://www.fs.fed.us/wwetac/projects/alexander.html>.

Reference

Alexander, M.E.; Cruz, M.G.; Vaillant, N.M.; Peterson, D.L. 2010. Towards a crown fire synthesis: what would you like to know and what might you be able to contribute? In: Proceedings of 3rd Fire Behavior and Fuels Conference, 25–29 October 2010, Spokane, WA. Birmingham, AL: International Association of Wildland Fire. CD-ROM. ■

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Some New Basics of Fire Behavior

Janice L. Coen

Forest fires create their own weather and can alter wind direction and speed near the ground surface over several miles (Coen 2005) as they interact with the surrounding atmosphere. Fires release heat and water vapor into the atmosphere, affecting winds, air pressure, humidity, and other meteorological conditions in the fire itself, the fire plume, and the fire environment. These effects, in turn, feed back on fire behavior, as the force of the winds modified by the fire directs the direction and speed of fire spread. We have learned that this two-way feedback is a basic component of all fire behavior—in plume-driven vs. wind-driven fires, high- vs. low-intensity fires, and crown vs. grass fires. Understanding the interplay of factors—particularly with the most variable one: weather—can help explain and anticipate fire phenomena, a necessary part of managing an evolving fire situation. Changing our perspective from seeing just the fire to seeing an interacting fire-air system is a new perspective in the fire management community, but because it is needed to explain even the most fundamental aspects of fire behavior, we consider it part of the new basics practitioners and scientists should understand about fires.

What Drives Fire

Three environmental factors have been widely recognized to influence wildland fire behavior: fuel, weather, and topography. Fuel factors include moisture content, mass per unit area, the size of the fuel particles, plant species composition, its continuity in space, and its vertical arrangement. Weather factors include wind, temperature, relative humidity, precipitation, and, particularly, meteorological changes such as barometric pressure fronts, down-slope winds, storm downdrafts, sea/land breezes, and cyclic diurnal winds. Important topographic features include the slope of the terrain, its aspect toward or away from the sun, channeling features such as narrow canyons, and barriers that might act as fuel breaks, such as creeks, roads, rockslides, or unburnable fuel. As traditionally described, these factors act separately upon the fire. In the new perspective, we recognize that these factors are not isolated, but affect each other in ways that ultimately affect the fire. For example, weather affects fuel moisture, vegetation canopy slows or adds gusts to the near surface wind, and weather (primarily atmospheric stability, wind speed, and wind shear) and terrain combine to produce the winds in nonflat terrain. Therefore, even the fire environment factors are not independent but part of a dynamic system.

Weather is often referred to as the "wildcard" in any fire event.

Among the three environmental factors, weather is the most rapidly changing and is often referred to as the "wildcard" in any fire event, as weather conditions over a wide range of time and space scales influence where a fire occurs (such as through ignition by lightning), the ignition efficiency, combustion rates, how fast and in what direction the fire spreads, and whether or not the fire produces extreme behavior. While weather can seem quite capricious and unpredictable, particularly in the vicinity of a wildfire, it is important to recognize that there are physical laws governing how air behaves. Familiarity with these basic rules provides understanding of a wide range of fire behavior previously thought of in terms of fire alone.

The "Rules" Governing Atmospheric Motions

To understand fire behavior, it is critical to understand that, even though air is an invisible gas, it is not empty space or "nothing." Air behaves like a fluid and has weight—even though it is approximately 1,000 times less dense than water, it follows the same physical laws of fluids—and, therefore, exerts force.

We experience the characteristics of air as air pressure, temperature, density, humidity, wind speed, and wind direction. Scientists distill these experiences with air into physical laws and express them in mathematical equations, but the concepts behind them

Dr. Janice Coen is a project scientist at the National Center for Atmospheric Research in Boulder, CO.

are understandable. One, a law of thermodynamics, states that energy can be changed from one form to another but cannot be created or destroyed. For example, as fire burns fuel, it releases energy into the air and the air temperature rises.

Another law, the ideal gas law, relates the pressure, density, and temperature of a gas such as air: increasing the temperature of a gas while keeping the pressure constant decreases its density and increases its buoyancy. Another principle, the conservation of momentum, is expressed in the Navier-Stokes equations of motion, which is Newton's second law applied to fluids—a body will accelerate proportionally to the force and inversely proportional to the mass. According to these equations, when the force of buoyancy is applied to the air, it must accelerate upward.

A third principle is the continuity of mass, that the mass of air cannot increase or decrease; it can only move from place to place. For example, when air moves upward in the fire plume, it cannot leave a vacuum—other air must move in at the bottom of the plume to replace it. Other equations express how the states of water vapor concentration (the conservation of water in the form of a gas mixed in dry air, related to relative humidity), water droplets, ice particle concentrations, smoke, and other particles will remain unchanged unless there is a material source or sink to generate or absorb it (e.g., fire as the source of smoke particles). When this set of equations is integrated and values are solved together, they make up a weather model that (1) provides a physically consistent and realistic state of the atmosphere, and (2) allows us to predict the fluid conditions in the future—in other words, predict potential weather conditions.

Phenomena Resulting From Fire–Weather Interactions

By recognizing the feedbacks of energy and momentum between wildland fires and the air in which they occur, we gain understanding into some well-recognized fire phenomena. Recognizing the patterns in fire behavior helps us anticipate expected and potential situations, with consequences to both the efficiency of attack and avoidance of dangerous situations.

An illustration of the airflow in the vicinity of a wildland fire is shown in figure 1. As the fire burns through fuel, it releases heat (both sensible heat—energy released as a change in temperature—and latent heat—energy that is released by a phase change, such as the condensation of gaseous water vapor into liquid water drops) and smoke into the air around it. Air heated by the fire rises, creating an updraft. The air in the plume accelerates upwards, expanding and cooling as it rises, until it is no warmer than the air at its height outside the smoke plume. If there is sufficient humidity in the environment and water vapor released by the fire, the moist air may condense into water drops and form a cloud (a "pyrocumulus"), which releases additional energy within the plume and pushes it upward. Eventually, the rising air will cool enough that it stops rising. Outside air over an area perhaps 10 times the size of the plume descends slowly and enters the plume at its base to replace air that has risen in the updraft, creating potentially strong currents of air into the base of the plume.

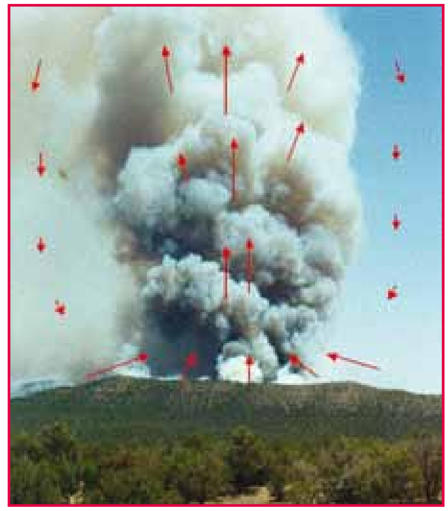

Figure 1—*Current understanding of flow in the vicinity of a large wildfire. The direction of arrows (added by the author) represent the direction of flow, and the length of arrows corresponds to the speed at that point. Photo: NIFC media library.*

This circulation of a strong plume surrounded by widespread weak sinking air is similar to the airflow in thunderstorms. And, as in thunderstorms, the plume will eventually die—either because the heat from the fire is cut off or the weight of raindrops in the plume drags the air in the updraft downward. The raindrops may evaporate in the drier air below the pyrocumulus, cooling the air, making it dense, and causing the air to accelerate downwards in a "downdraft," which can impinge on the surface and speed outward, causing gustiness at the fireline.

Fire whirls that form along the edges of a fire vary over a wide range of sizes, including small whirls filled with flames (fig. 2), tall flame-filled whirls (fig. 3), and whirls that resemble tornadoes (fig. 4). These vertical columns of fire arise from the heat produced by the fire along an irregular fireline. As heated air rises, the difference in temperature across the fireline draws colder air inward laterally, creating a rotational movement along the edge of the fire. This rotation is tilted upward by the updrafts and is tightened as the rising air pulls it into a spiral.

The elliptical shape of fire fronts arises from fire–atmosphere interactions. For example, the Onion Fire (fig. 5) was roughly a line of fire when a light wind (from behind the image) pushed it forward. Instead of spreading in a line, the fire evolved into a series of fingers of fire, "convective fingers," each approximately 0.6 miles (1 km) across. When the winds died down, the fire consumed the fuel in the areas between the fingers, filling in the gaps in the fireline to reform a straight line. This phenomenon, too, can be understood using the principles of fluid flow previously described.

Figure 2—*A fire whirl observed during the International Crown Fire Modeling Experiment, 1997. Photo: Canadian Forest Service.*

Figure 3—*A fire whirl seen during the Day Fire, California, 2006. Photo: Jeff Zimmerman, Southern California Fire Journal.*

Figure 4—*A "firenado" photographed during the Day Fire, California, 2006. Photo: Joshua Harville.*

Detailed studies of convection (that is, the vertical transfer of heat away from the fire by the movement of air) show that, as fire intensity grows, convection becomes more vigorous; the heat cannot rise as a continuous unbroken line but breaks up into circular cells as numerous vertically oriented plume updrafts occur along a fireline. The increase in the ambient wind thus increases the heat flux into the atmosphere, causing the upward movement of air to break into cells, and pushes the updraft cells slightly ahead of the fire, as shown in the inset to figure 5. Each updraft continues to draw air in from all directions at its base to replace the air rising in the plume, pulling the fire front forward. Each convective cell (or plume updraft) forms one of the bow-shaped fingers. Between the cells, the fireline receives air diagonally, which constrains the forward rate of spread at those points. As the ambient wind decreases, fire intensity decreases, the updraft cells weaken and are no longer pushed ahead of the fire, and the fireline fills into a straight line again.

These edge effects can be reproduced with certain types of computer models that couple weather models to fire behavior. These show that, under an ambient wind of a few miles per hour, a straight fireline will bow into these convective fingers (Clark and others 2005) (fig. 6). In those simulations, begun with a short fireline in weak uniform winds, two interesting effects were noted. First, although the winds in the fire environment began as uniform light winds from behind the fire (fig. 6a), the interactions of the fire and the atmosphere *caused* the fire to shape itself into a bowed shape with a rapidly spreading head, flanks along which winds were blowing parallel towards the head, and a weak intensity backing region creeping slowly against the wind (fig. 6b). Second, fire whirls were simulated along the fireline. In these simulations, a small perturbation in fire spread along the fireline would cause a little perturbation in fire spread, which would consume a little more fuel than points along the line near it, release a little extra heat, and create a slightly stronger updraft, tilting and stretching the already present rotation we described earlier into a rotating fire whirl. In the winds shaped by the fire to be parallel to the fire flank, the fire whirl was brought forward to the fire head. Fire whirls may linger there or interact with fire whirls brought forward along the other flank. Clark and others (2005) suggested that such fire whirls may be drawn together, hook together at the top, and roll forward in flaming bursts.

More dramatic examples of fire behavior resulting from fire-weather interactions are the narrow fingers of flame that shoot forward along the ground surface ahead of the fireline at speeds of 100 miles per hour (170 km/h). Although not currently included in fire training materials, they have been detected

The common elliptical shape of fire fronts arises from fire–atmosphere interactions.

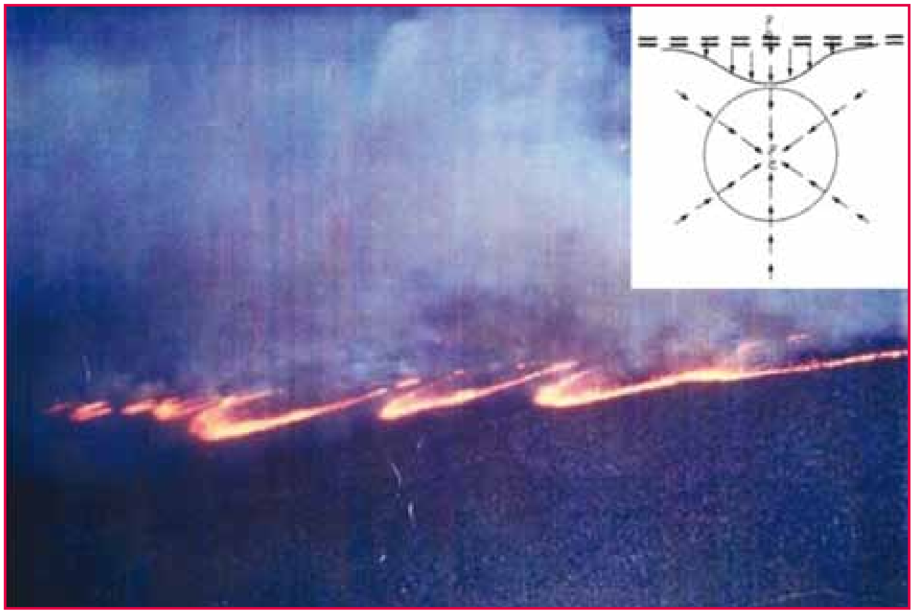

Figure 5—*The Onion Fire in Owens Valley, California. The inset shows the mechanism for a fireline bowing into the widely observed elliptical shape, as seen from above. The dashed lines represent the original straight fireline; the arrows represent the speed and direction of winds near the surface; the circle represents the convective plume created by the fire; and the bowed line represents the fireline drawn forward by the winds being pulled into the base of the updraft. Photo: Charles George, USDA Forest Service. The inset is reproduced from Clark and others (1996).*

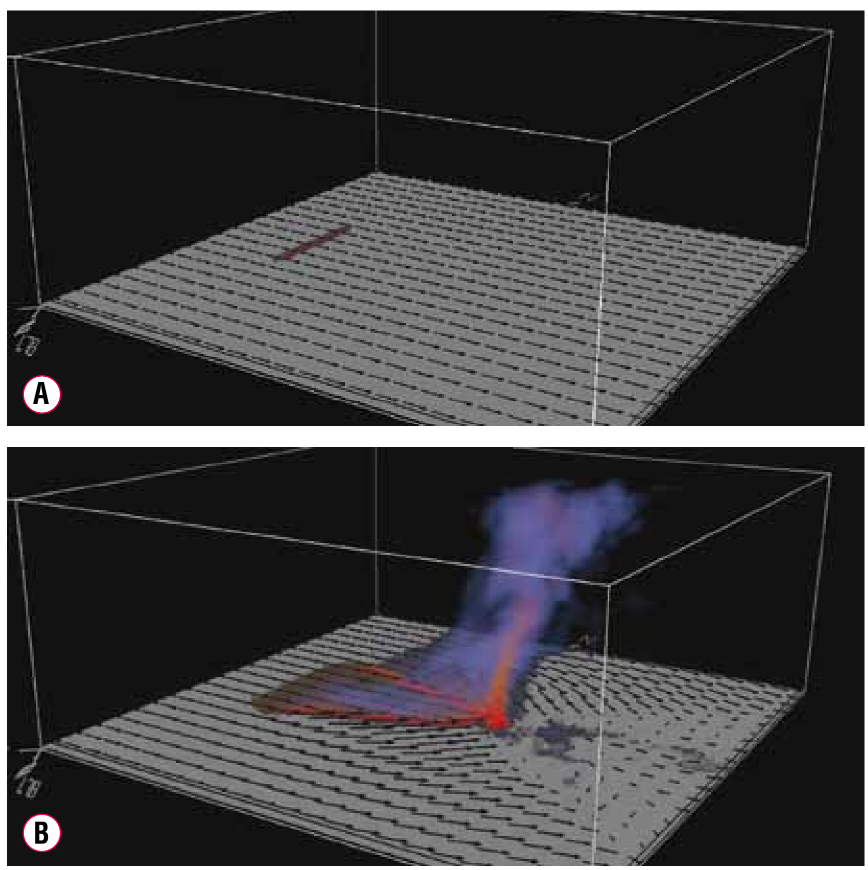

Figure 6—*Plots of buoyancy (red) and smoke (purple). The arrows represent the length and direction of the winds near the surface at (a) ignition of the fireline and (b) 25 minutes later. Illustration: Janice Coen.*

from both aircraft-based observations (Radke and others 2000) (fig. 7) and ground-based observations (Coen and others 2004) (fig. 8) of crown fires climbing slopes so frequently that we believe this is a widespread phenomenon. As crown fires climb slopes, the fire bows forward into the common bow shape, and fingers of flame are observed to shoot forward along the surface at speeds approaching 100 mph (170 km/hr) for 100 yards (91 m) before turning upwards and dissipating, the whole event lasting less than 2 seconds. These bursts exceeded the ambient windspeeds by a factor of 10 and likely result from vortex interactions. Their repeated occurrence—preheating, drying, and igniting the surface fuels and canopy—no doubt contributes to the rapid spread of crown fires.

The wide range of observations of this phenomenon suggests it is a fundamental part of fire behavior. This powerful, dynamic mechanism is likely behind fatality reports of firefighters ahead of the fireline being overtaken by "fireballs" or "knocked over and burned" by a sudden blast of flame or hot air.

Figure 7—*Infrared image of the MacDonald Creek Wildfire (where hotter radiant temperatures are yellow and white, and cooler temperatures are red and dark red) traveling upslope (towards the upper right corner) at the instant when a flaming finger shot from the leading edge of the fireline. Photo: Janice Coen.*

More dramatic examples of fire behavior resulting from fire-weather interactions are the narrow fingers of flame that shoot forward along the ground surface ahead of the fireline.

This phenomenon poses an unanticipated safety hazard, deceiving crews that the distance between them and a fire downslope from them leaves time to deploy a safety shelter—until it becomes common knowledge that such features can leap ahead of the fireline and that one does not have to be overtaken by the fireline to be harmed.

Putting Science to Use

Computational modeling and analysis of infrared imagery have been revealing new phenomena and reasons *why* fires behave as they do. This new understanding brings together what atmospheric scientists have learned about weather and air motions with what fire scientists have wanted to know about

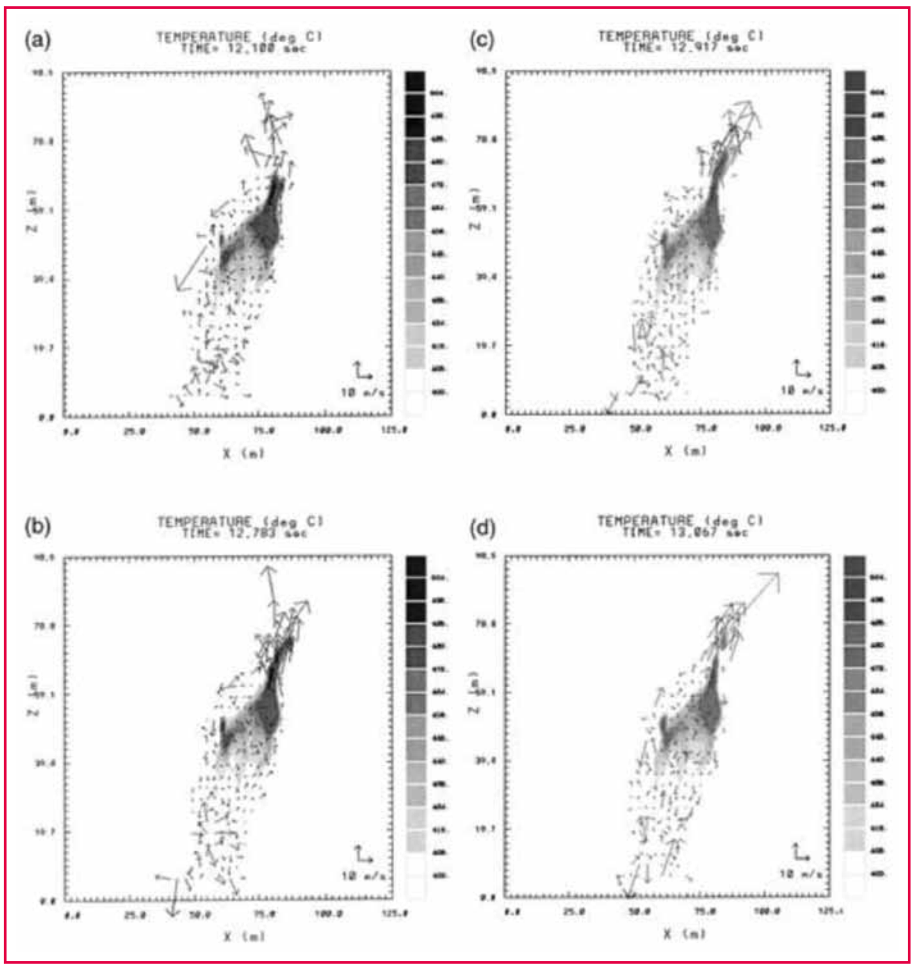

Figure 8—*Analyzed infrared imagery of a prescribed crown fire during the FROSTFIRE experiment traveling upslope towards the upper right during the 2 seconds during which a flaming burst shot forward along the surface and then dissipated. The arrows represent the analyzed winds. The colors represent the measured radiant temperature, where darker colors represent higher values. Plots: Janice Coen.*

how fires spread, why firelines are shaped as they are, what causes their erratic behavior, why they blow up, why there are runs along the flanks, why some fires are wind-driven vs. plume-driven, why they run up canyons, and other aspects considered part of fire behavior. Many aspects of fire are difficult to predict—particularly, as fire itself can dictate some of the immediate weather conditions that support and spread it. The study of fire behavior is inseparable from the study of local weather behavior. It simply remains to make this new understanding part of fire management planning.

Acknowledgments

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