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Tuesday, November 18, 2003

Wildland Fire Operations Safety – A Comprehensive Program to Change a Culture 5

Redesigned Fire Shelter Now Available for Wildland Firefighters 8

Assessing the Need for Footwear with Protective Toecaps for Wildland Fire Operations in Alberta 12

Loggers and Logging Equipment to Fight Wildland Fires: Issues and Opportunities in Oregon 14

Hazard Tree and Snag Safety 18

Wednesday, November 19, 2003

Aviation Safety on the Fire Line 22

The Safe and Economic Structural Health Management of Airtanker and Lead Aircraft Involved in Firebombing Operations 25

Improving Aerial Operations Safety 29

Knowledge Management in the Wildland Fire Community 32

Predicting Spatially Explicit Burn Probabilities Across Forest Landscapes Under Extreme Weather Conditions 36

High Resolution Surface Wind Simulations in Complex Terrain 40

A Low Cost Weather/Situation Monitor for Wildland Firefighter Safety 44

Keeping it Fresh: Fire Behaviour Safety Messages During Extended Fire Situations 48

Thursday, November 20, 2003

Improved Pulaski and a Safer Hand Tool System & Strategic Positioning to Eliminate Loss in the Interface 53

The Use of Leading Indicators to Measure the Performance of the Occupational Health and Safety System 57

Fire Behaviour/Safety in Mountain Pine Beetle Killed Stands in British Columbia 61

Wildland Fire Operations Safety –
A Comprehensive Program to Change a Culture

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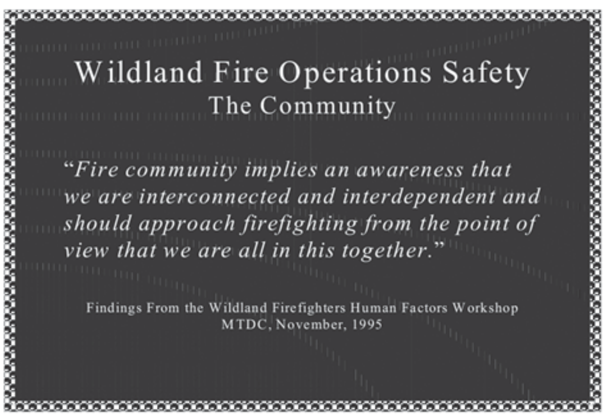
The Goal

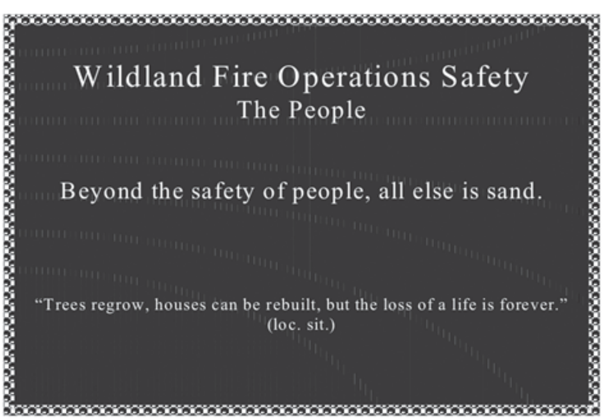
Operational error is inevitable. The key to error resistance is to move away from conceptualizing safety as a goal, to realizing it as a result of sound operational practice, solidly anchored and guided by strong and consistent organizational values.

The Community



Every success and every failure on the fireground is a success or failure of the fire community. Where there is a failure, there is failure in the entire system. Where there is a solution, it involves the entire system.

The People



Our very nature (that part of our nature that attracted us to this business in the first place) impels us to take personal and corporate risk when lives, property, and our natural heritage are threatened. Our preeminent concern for firefighter safety requires an emphasis on strong leadership, a comprehensive operational approach, and focused action.

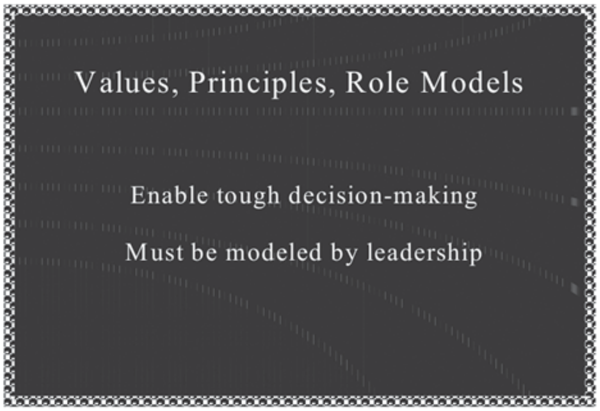
The Concept

The fire environment is risk filled and constantly changing, and the role of incident management personnel is rapidly expanding. The challenge is to mold and direct present-day firefighters into a highly effective firefighting workforce, one that is highly productive and inherently safe.

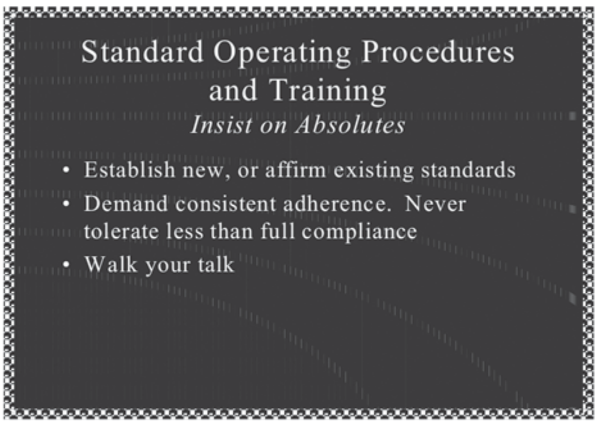
The Application

In order to become error resistant, an organization must focus on five key areas:

Values A foundation of solid, shared values enables fire organizations to set decision parameters concerning risk and benefit. Values help guide others in crafting policy decisions toward expected outcomes, guide the leadership, training, and expectations of others, and stabilize the organization as the political winds blow.

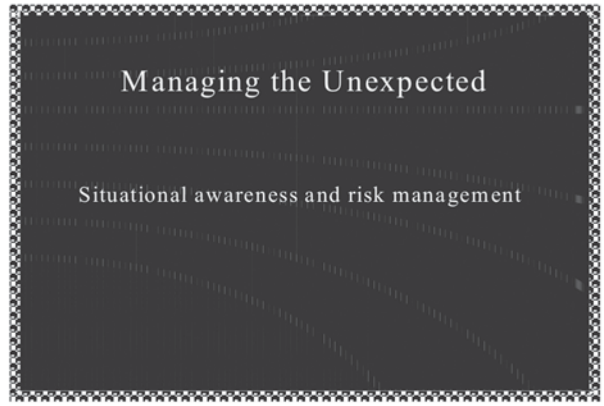


Absolutes Insist on absolutes; establish new or affirm existing standards, and demand professional, focused, and consistent adherence to them, never tolerating less than full compliance. Absolutes become firm rules of engagement, an organizational standard, and shape the identity of the organization.



Bias for Action Policy and rules cannot cover all the possible situations in the complex work environment of wildland fire suppression. Uncertainty and ambiguity are pervasive characteristics in nearly all fireline decision-making. Safe and effective firefighting requires a bias for action, realizing every tactical maneuver is predicated on accurate situational awareness, rapid and pinpoint risk identification and mitigation, and thoughtful, mindful decision making.

Managing the Unexpected Organizations that are the most effective also tend to have the best safety record. Crews/teams/units that are resilient, effective, and safe maintain a healthy suspicion of situations that appear to be routine, realizing the unexpected can happen and planning for it.



Leadership The fundamental building block of an error resistant firefighting workforce is leadership. Leaders are the source and teachers of culture, values, attitudes and behavior.

It is critical that we reorient our training emphasis to human decision-making, leadership, and communication.

Summary

An error resistant organization is one that has established well-known, accepted, and practiced values. It provides emphasis and resources to constant drilling of learned skills in a realistic environment. It is an organization that maintains and insists on adherence to operational absolutes, displays a bias for thoughtful and mindful action, and is dedicated to developing its future leaders today.

NOTES:

Redesigned Fire Shelter Now Available for Wildland Firefighters

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Introduction

The fire shelter is an element of personal protective equipment used by wildland fire fighters in the United States. Fire shelters are carried as a last resort to protect against heat injury during a wildfire entrapment. The fire shelter was completely redesigned at the U.S. Department of Agriculture Forest Service's Missoula Technology and Development Center (MTDC) between 2000 and 2002. Distribution of the new shelter design began in June 2003.

The original fire shelter design, here referred to as the standard fire shelter, has been in use for over 30 years. It is made of a laminate of fiberglass cloth and aluminum foil in the shape of a pup tent. It has saved more than 300 lives and prevented a similar number of serious burn injuries. The standard shelter offers protection by reflecting radiant heat. However direct flame contact could rapidly damage the shelter. Fatalities have occurred when flame contact was severe.

The new fire shelter was designed to offer fire fighters better protection from flames and convective heat while maintaining or improving the protection from radiant heat offered by the standard shelter. Considerations of weight, bulk, strength, durability, ease of use, and potential toxicity were also critical to the selection of the new shelter.

Approach

The first step in the development process was to devise tests to evaluate the performance of the prototype shelter materials and designs. With assistance from the departments of Human Ecology and Mechanical Engineering at the University of Alberta in Canada, and private laboratories in the United States, small-scale laboratory tests were designed to allow screening for strength, flammability, thermal performance, and toxicity of materials. Full-scale tests were developed to measure the strength, durability, flammability, thermal performance, and toxicity of the overall shelter designs.

In all, over 60 materials were considered for the new shelter. Materials showing potential for use in a fire shelter were first tested in the small-scale. Seventeen different materials were then selected for testing as full-scale prototypes. Interest from private industry in the development of a new shelter was high. Most of the private companies that submitted materials for consideration had expertise in fire protection, but had little background in the requirements of a fire shelter. So MTDC developed a fire shelter design that would allow testing of promising materials in the full-scale. Most of the materials selected for full-scale testing were sewn into shelters using the MTDC design. One company, Storm King Mountain Technologies (SKMT), submitted fully-designed shelters for testing. The SKMT shelters were tested in the form in which they were received.

Results and Discussion

Based on the results of the small- and full-scale testing, the Federal Fire and Aviation Leadership Council, made up of fire managers representing the U.S. Departments of Agriculture and Interior, and State agencies with responsibilities for wildland fire management, selected the final shelter design in June 2002.

The new shelter is made of two layers of material. It weighs 4.2 pounds, compared to about 3.4 pounds for the standard shelter. The outer layer is woven silica laminated to aluminum foil. The inner layer is fiberglass laminated to aluminum foil. The outer layer of foil reflects radiant heat and the woven silica slows heat transfer to the inside of the shelter. The inner layer of foil prevents heat from being reradiated inside the shelter, and it prevents gases from entering the shelter. When the two layers of material are sewn together, the air gap between them provides additional insulation.

The shape of the new generation shelter differs from that of the standard fire shelter (figure 1). The shelter is now shaped like a half cylinder with rounded ends. The new shape has a number of advantages. The rounded design reduces the surface-area-to-volume ratio, decreasing the amount of material needed to provide enough volume inside the shelter. The new materials improve protection from flames, but they weigh twice as much as the old materials. If the new materials had not been used efficiently, the new shelter could have weighed more than twice as much as the standard shelter.

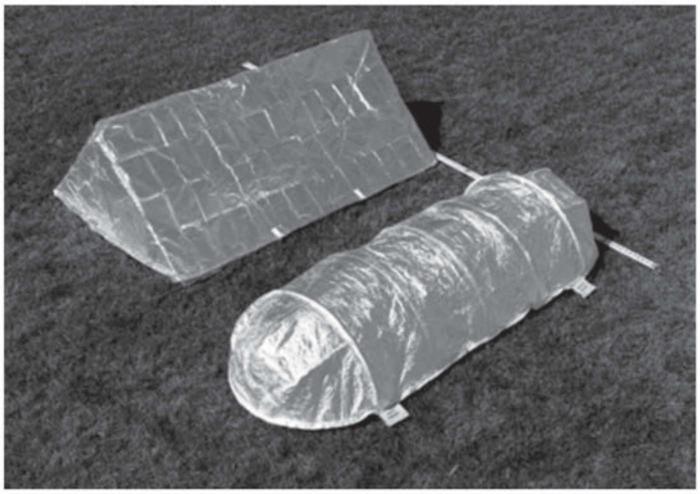

Figure 1—The new generation shelter (right) is longer, rounder, and lower than the standard shelter.

The new design's reduced surface-area-to-volume ratio means improved protection because the shelter has less surface area to absorb radiant heat. The rounded ends also solve a problem noted during field-testing of the standard fire shelter. Video taken during test fires showed that the flat ends of the standard shelter could reflect heat onto adjacent fuels, igniting them before the flame front arrived. Flames from adjacent fuels could damage the shelter, reducing the level of protection offered when the flame front arrives. The rounded ends of the new shelter design scatter radiant heat to the atmosphere, rather than focusing heat on fuels next to the shelter.

Seams across the top of the shelter support the shelter's main shell. The seams also help keep the outer foil layer in place. When the shelter is heated to 260 ¡C (500 ¡F), the adhesive that bonds the foil to the silica breaks down, allowing the layers to separate. In turbulent conditions, the foil can tear and peel away from the silica layer. Seams protect the foil layer because the foil stops peeling when it reaches a seam.

The new shelter has "shake handles" to speed deployment. If the user grasps the handles and shakes, the shelter will unfold quickly. Holddown straps are located alongside the opening where firefighters can slip their hands through them when deploying so they can hold the shelter down in strong winds.

Performance—Testing in radiant heat and direct flame are critical when assessing a shelter's ability to limit heat transfer. The greatest threats a firefighter faces during an entrapment are burns to the body and inhalation of hot gases, which can cause asphyxiation. The inhalation threat was assessed by measuring the temperature at various locations inside the fire shelter. The potential for burns was assessed with temperature and heat flux measurements inside the shelter.

The new shelter provides improved protection from both radiant heat and direct flame. In radiant heat tests using full-scale designs, temperatures inside the new generation shelter rose 22 percent less than temperatures inside the standard shelter after 300 seconds. The temperature rose an average of 76 ¡C (169 ¡F) in the new generation shelter compared to 97 C¡ (207 ¡F) in the standard shelter. In direct-flame tests, temperatures inside the new generation shelter rose 81 percent less than temperatures inside the standard shelter after 40 seconds. The temperature rose an average of 56.5 ¡C (134¡ F) inside the new generation shelter, compared to 300 ¡C (572 ¡F) inside the standard shelter.

In radiant heat tests, the average peak heat flux was reduced 59 percent, from 3.7 kilowatts per square meter for the standard shelter to just 1.5 kilowatts per square meter for the new generation shelter. In direct flame tests, the average peak heat flux for the new generation shelter was 97 percent lower, just 1.3 kilowatts per square meter, compared to 44.1 kilowatts per square meter for the standard shelter.

Training—Since deployment of the new generation fire shelter is somewhat different from deployment of the standard shelter, firefighters should not carry the new generation fire shelter until they are properly trained. To facilitate training, MTDC has developed a new training video (also available as a DVD), a new training pamphlet, and a new practice fire shelter.

Conclusion

Finally, a caution. The new generation fire shelter provides a significant improvement in the level of protection wildland firefighters will have in the event of an entrapment, but it does not guarantee survival. Carrying a fire shelter should never be considered an excuse to take chances on the fireline. A firefighter's highest priority is still to avoid situations that can lead to entrapment.

NOTES:

Assessing the Need for Footwear with Protective Toecaps for Wildland Fire Operations in Alberta

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The wildland fire environment is severe and footwear must withstand contact with embers with temperatures up to 400 degrees C, exposure to corrosive substances, and frequent emergence in water. These boots must also provide ankle and foot support. Recognizable hazards include uneven terrain, slippery footing, obstacles and tripping hazards, and slips, twists, cuts and abrasions are common injuries.

The primary performance requirement for footwear to meet the Canadian Standard Association's CSA Z-195 M 92 standard is a protective toecap, usually provided by a steel toecap. Alberta wildland firefighters believe impact and cut injuries to the toes are a minor hazard and question the appropriateness of safety toe footwear for general fireline tasks.

Recommendations and Conclusions

Under Alberta General Safety Regulations, Part 5 Personal Protective Equipment, Foot Protection, if a danger of injury to a worker's foot is minor, the worker is not required to wear CSA Z195-M92 foot wear. Hazard assessment and risk analysis of fireline tasks performed by Alberta wildland firefighters indicate a minor danger of impact and cut injuries to the foot, therefore CSA footwear is not required.

Further, this study found the CSA Z195-M92 standard design and performance requirements are unrelated to the conditions found in the wildland fire environment where slips, trips, and falls are the primary hazards. Research indicated boot fit for a number of firefighters can be compromised by the selection of steel toecaps. Proper fitting footwear is more important than toe protection. Footwear appropriate for the fireline should be designed to provide traction in a forest environment, should allow the foot the fullest range of movement while providing stability for the ankle, and should be constructed of materials that are flame resistant. Suitable footwear for the wildland environment can be found in both CSA and non- CSA footwear. This study recommends that the Alberta Forest Protection Division clarify its Wildfire and Aviation – Protective Clothing Policy FPD 4.2 to require footwear on the fireline to include the following:

- Soles designed with an aggressive lug/tread pattern
- Soles manufactured of rubber or composite rubber compounds
- Boots of a minimum height of 20cm (eight inches).

The policy should be specific in its requirement for both leather boots and water resistant boots. Leather boots must provide ankle support and a proper fit.

The use of water-resistant footwear on the fireline should include a requirement that only footwear manufactured of flame-resistance materials be allowed.

In the absence of a Canadian standard specifying minimum design, performance, testing, and certification requirements for wildland fire footwear, the Protection Division should provide its firefighters guidance in the selection of appropriate footwear.

The National Fire Protection Association 1977 standard of a suitable leather boot should be considered for Alberta firefighters. This standard allows each agency to specify boot outsole requirements to reflect terrain features.

Manufacturers have indicated an interest in working with Alberta Protection Division in the design and production of footwear to meet the needs of wildland firefighters. This is an opportunity for the Protection Division to advance the development of high performance, fireline-specific footwear to minimize the overall number of fireline injuries.

NOTES:

Loggers and Logging Equipment to Fight Wildland Fires: Issues and Opportunities in Oregon

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Introduction/Objectives

Recent fire seasons have been devastating with lives lost and millions of acres burned in Oregon alone. Contract loggers often have a strategic proximity to aid in initial attack. Research efforts to explore these possibilities in Oregon are addressing safety regulations pertaining to workers, developments in logging machinery to fight fire, and training concerns. The current fire situation throughout the western U.S. continues to make this line of research important for the firefighting community.

Since 1988, the Oregon Occupational Safety and Health Administration (OR-OSHA) safety code has specifically addressed the wildland firefighter as an employee of a firm operating within Oregon. While responding to fires on logging operations, employees are of course employed by contractors or the landowner. When fires on private land become state responsibility, firefighters are considered employees of the Oregon Department of Forestry. While fighting fires on federal lands in Oregon, the Interagency Fire Command Structure uses contractors who have employees covered under OR-OSHA codes. While the federal safety code still relies on the general duty clause and other safety standards, OR-OSHA regulations covers thousands of Forest Activities workers, including hundreds of private and agency firefighting crews. An industry-based safety code review committee is currently updating the proposed regulations to include new machinery applications and other fire activity code issues.

Logging uses advanced technology to make forest operations more efficient and some of these innovations are finding a role in firefighting as part of the process. For example, felling machines are used in place of timber fallers, and hydraulic excavators are used to move timber and vegetation along with bulldozers to build firelines. Forwarders are now equipped with auxiliary tanks to make large quantities of water available in difficult terrain for hose lays, with additional foaming devices and water cannons. Likewise, skidders have tanks attached and become "skidgines" on the firelines. The objectives for research are to:

- Document the applications and uses of modified logging equipment used in firefighting
- Provide knowledge of equipment use to agencies and firefighters including slope stability issues and potential applications for timber types
- Interact with machine manufacturers through the Society of Automotive Engineers (SAE) Forest Machinery Subcommittee to gain their views on use of equipment in firefighting
- Assess policies for using logging crews and equipment on fires, especially regarding training for initial and extended attack
- Provide input to the OR-OSHA for rule development concerning wildland firefighting.

Approach

We are collecting information on the use of modified logging equipment used for firefighting on public and private lands to assess problems and opportunities. With such adaptations like auxiliary water tanks on forwarders, engineering analyses and stability models are needed to determine safe limits of machinery use on difficult terrain. The OR-OSHA committee and the SAE Forest Machinery Subcommittee are reviewing guidelines for these new technologies, and a survey is planned for the Subcommittee. Another critical issue is the training and structure of fire suppression management and the incorporation of loggers. While loggers have valuable skills in timber falling and machine operation, they may have minimal knowledge of fire behavior or fire organization for suppression. What steps are needed for a logging crew adjacent to a lightning strike to take action and extinguish the fire? How would such attacks integrate with the coordination of the responding agencies and the transition to an extended attack scenario? A review of needed training, personal protective equipment, and coordination among organizations is underway to see how such a process could work. We expect to summarize our findings in a report to the U.S. Forest Service who is providing funding for the project and to publish the results.

Results and Discussion

Because Oregon loggers are required by law to make a "reasonable effort" to suppress fires resulting from their operations, they take firefighting seriously. For example, "skidgines" follow tracked hot saw machines during operations to immediately suppress fires caused by track or saw sparks. Various forwarder tank designs have been successfully used on wildland fires, but there is little knowledge among the fire command structure how such equipment can be employed. Other modified logging equipment may not be recognized as well.

Mobility and stability models at Oregon State and Auburn University show the effects of slope, auxiliary tank placement, and machine design for fire operations. Safe operating procedures can be developed from the basic information. Results from the survey of SAE Forest Machinery Subcommittee should be available later this year.

The new OR-OSHA Division 7 Forest Activities Code becomes effective December 1, 2003 and includes provisions covering employers and employees engaged in wildland fire fighting. Some fire contractors were surprised to learn that they are responsible for all of the provisions of Division 7 safety codes unless exempted. Provisions covering fire training for logging crews are at present unchanged, but other provisions, such as machine guarding requirement and operating conditions, will be applicable.

The training for wildland firefighting in Div. 7 consists of a one-day (typically video based) training on general fire behavior and control, personal protective equipment, tools and equipment, laws and regulations, and communications/lines of authority. Some logging contractors provide additional training beyond that required by OR-OSHA and may include week long courses. However, most logging contractors do not provide the training needed to meet the Federal Interagency firefighting contract in full unless they are also engaged in agency contract fire suppression.

The OR-OSHA Fire Subcommittee is still meeting to address potential rule changes regarding wildland firefighting. Once rules are considered by the full OR-OSHA Committee, they must be submitted to public hearings, testimony and final rule-making.

Conclusion

Our research is still ongoing but some preliminary findings are noteworthy. Anecdotal evidence suggests modified logging equipment can make successful contributions to firefighting ranging from mechanized felling, water delivery, fireline construction and direct suppression. The "Proteus" is the most recognized example of such equipment. However, fire managers need much more information and experience with modified logging equipment to effectively dispatch and utilize it.

Because of contract provisions regarding personal protective gear, heavy equipment approvals, and training requirements, it is often difficult for logging crews to continue firefighting after an agency responds to the incident—especially on federal lands. Meeting the OR-OSHA Div. 7 Code requirements does not qualify logging contractors for fire suppression on federal agency fire incidents. Conversely, not all fire contractors may be meeting the full OR-OSHA Forest Activities Code requirements at present.

Modifying logging equipment for firefighting without taking into account design conditions of machine stability could lead to hazardous operations. Sticking a tank on a skidding machine without considering overall machine stability would not be recommended. Machine manufacturers may have something to say about the uses of machines they designed for uses other than firefighting.

As large fires persist in the west, fire suppression is continually changing. The potential for using logging personnel and equipment to fight wildland fires is an important firefighting option.

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NOTES:

Hazard Tree and Snag Safety

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Hazard Tree Safety: "Up the Ante", and "An Interactive Study"

Up the Ante led to *Hazard Trees- An Interactive Study*. The program today is a discussion of how we solicited ideas from the people on the ground, and how the new Power Point presentation emerged from there.

Up the Ante

Originating in the Northern Rockies, *Up the Ante* builds awareness by challenging employees to find new solutions. This employee participation process reviews existing guidelines and rules, and seeks improved policy and procedures.

The questions presented on a note-taking page are:

- ***How well are we practicing current guidelines?***
- ***How adequate are the existing guidelines?***
- ***Is it realistic to expect people to be mindful and in compliance with these guidelines at all times?***
- ***New Directions***
  - ***Generate new ideas to prevent hazard tree tragedies***
  - ***Suggest simplified format for guidelines***
  - ***Suggest programs, publications and research***
  - ***Assign individual(s) to prepare local hazard tree briefing paper***

Findings from each unit are e-mailed to a central address.

Up the Ante is a first step. We survey the workforce, and receive our marching orders. Many outstanding suggestions emerge for a continuing program. A report, *Up the Ante, Winter 2003 Progress Summary,* compiles findings to date, and profiles elements of a comprehensive hazard tree safety program. It is available on the web-site.

The Hazard Tree web-site is an important element. Up the Ante is described, and a growing library and internet links for related reference material is available for everyone.

Hazard Trees- An Interactive Study

Hazard Trees- An Interactive Study is a new Power Point slide presentation that combines the work of Kim Johnson's *Potential Green Tree Hazards* and findings from the workforce attained in *Up the Ante*. Co-authored by Kim Johnson and Paul Chamberlin, participants study universal *Indicators*, and then learn to focus their attention on the *Crown*, the *Bole*, the *Ground*, and *Changing Conditions* around them. Structural issues, change factors, and basic techniques to further investigate indicated concerns are woven with participant discussion of three risk levels. Appropriate mitigations for each level of risk are identified by participants. The three risk levels are:

1) Walking, riding or driving by
2) Temporary exposure such as firefighting and mop-up, trail construction, fishing, camping the night, etc.
3) Permanent risk such as a public campground, a permanent building, main road, etc.

An Interactive Study is charting direction towards a comprehensive hazard tree safety program. A strategy of informative and interesting material presented in an interactive group dialogue avoids 'safety by checklist and documentation'.

Employees, volunteers, contractors and forest visitors will find this a valuable tool.

- ***Success is achieved when wise, concise, and achievable concepts become part of the culture.***

- ***Success is achieved when these concepts become regular briefing elements, and is found, with common language, in manuals, guidebooks and safety posters.***

- ***Success is achieved when conscious and deliberate procedures and behaviors end tragic hazard tree accidents.***

Find this work at www.fs.fed.us/r1/forest_range/hazard_trees/home.htm

Hazard Trees- An Interactive Study is #18 in the reference section.

NOTES:


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Aviation Safety on the Fire Line

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Introduction:

Aviation is a key element in the success of fighting fires in Ontario. The Ontario Ministry of Natural Resources – Aviation Safety section has developed a set of Standards that are above the Federal requirements to ensure the safety of staff working in a fire environment.
Helicopters are the most widely used tools in all fire line operations and will be the general focus on this topic.

Approach:

The Standards and Requirements for the Government of Ontario Approved Air Operators known as "The Standards" were developed. These standards were not intended to detract, infringe or abrogate from the provisions of the Aeronautics Act and the Rules and Regulations promulgated pursuant to the Aeronautics Act.
"The Standards" were designed to ensure that all Air Operators are required to meet minimum safety requirements as dictated.
To be eligible to work in Ontario, the Air Operator must meet the following criteria.

a) Auditing and assessing to ensure compliance to "The Standards" of Operators, their aircraft, facilities, practices, procedures and records, etc., will be conducted by the Aviation Safety section.

b) Regulatory Requirements include No Smoking in Aircraft, Fuelling, Pre-board Briefings, Emergency Locator Transmitter (ELT), Flight and Duty Times, Dangerous Goods, Cargo Restraints, Maintenance, Engineers, Environmental Concerns, and Alcohol and Drugs.

c) Insurance – All Air Operators will provide legal liability coverage including without limitation, passenger and third party liability insurance in accordance with all applicable laws of the Province of Ontario and the Dominion of Canada.

d) Pilot Standards – minimum aircrew qualifications for Rotary and Fixed Wing aircraft.

e) Occurrence Reporting - involves reports from both Fire and Aviation staff, which are submitted immediately to the proper authorities.

Discussion:

Through the auditing process, if at any time the Air Operator is not properly configured in accordance with all applicable laws and regulations or does not meet "The Standards", they will be removed from the Eligibility list and if on hire at the time, the hire will be terminated.

Regulatory requirements have been expanded from the Canadian Air Regulations. Areas such as flight times have been limited to 8 hours per day and consumption of alcohol prior to a flight was increased to 12 hours.

Minimum liability Insurance stands at five million unless otherwise stated in a contract or tender. Their coverage must include endorsements with Her Majesty the Queen in the right of Ontario, Cross liability, Subrogation and cancellation clauses.

Aircrew minimum qualification in general speaks to the total amount of hours that the pilot has flown. For all helicopter operations on the fire line the pilot in command (PIC) must posses a valid commercial licence and has a minimum of:

- 1000 hours rotary wing flight time
- 200 hours with experience in working in unprepared and confined areas
- 100 hours Pilot-in-Command on similar type of which 25 hours must be current Pilot-in-Command on type, or a valid Pilot Proficiency Check (PPC) on type, or valid Pilot Competency
- Check (PCC) on type in the preceding 30 days
- Flight time on type within the preceding 60 days

- Occurrence is defined in the Aeronautical Information Publication (AIP)

(a) any accident or incident associated with the operation of aircraft; and

(b) any situation or condition that the Transportation Safety Board has reasonable grounds to believe could, if left unattended, induce an accident or incident.

This definition has been expanded to reflect the needs and requirements of the Ministry of Natural Resources, which includes;

(a) any circumstances in which OMNR Aviation Policy has been breached;

(b) any situation which is likely to cause embarrassment to the crown;

The fire function on line is the Aviation Operations Branch Director (AOBD) and in conjunction with continuous audits from the Aviation Safety Officers ensures that "THE STANDARDS" and all safety concerns are immediately dealt with. This type of management strategy strengthens the relationship between management and the fire line workers.

Conclusion:

Without the vast amount of occurrence reports from the fire line staff, data could not be gathered to assess the shortcomings of each program or safety deficiencies. Through the educational requirements for all fire fighters, the aviation safety section has proven to be a proactive tool to increase the level of awareness for safety.

Aviation Safety and the Fire Management Sections are two distinct professional groups that have come together for one common goal "SAFETY". The number of incident reports versus any major occurrences in the helicopter operations is an indicator of the outstanding communication level. This relationship continues to foster the highest level of Aviation Safety in all areas from the fire line right to the head office.

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The Standards and Requirements for the Government of Ontario Approved Air Operators
("THE STANDARDS") Revision #2

NOTES:

The Safe and Economic Structural Health Management of Airtanker and Lead Aircraft Involved in Firebombing Operations

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Introduction:

Firebombing aircraft in general and large airtankers in particular play a vital role in the containment of large forest fires in North America and a number of other countries. Many of the aircraft utilized in this role were never originally designed for continuous use in such an aggressive low-level role. Consequently, over time, unexpected or unanticipated structural problems can arise, the consequences of which often prove to be catastrophic.

The impact of continued firebombing use on the structure of an aircraft was tragically illustrated during the 2002 fire season. Two large airtankers in the U.S. Firebombing fleet suffered catastrophic in-flight wing failures within a month of each other while participating in firebombing operations in the American South-West. The failures resulted in the loss of both the crew and the aircraft. Aside of the personal tragedy associated with these losses, the immediate and long-term impact on the availability of firebombing assets was dramatic and costly. Between ten and fourteen large airtankers were immediately grounded for the remainder of the 2002 fire season. Subsequently, all large airtankers were restricted to operating at 15% below their maximum capacity during the 2003 fire season. While these actions were necessary, pending the outcome of a number of investigations, they resulted in limited airborne resources becoming even more strained and a significant loss in operational firebombing capability.

In the aftermath of the accidents the United States Department of Agriculture Forestry Service (USDA/FS) initiated a Blue Ribbon Commission to evaluate the "structural health status" of the United States firebombing fleet. The commission, which reported their findings, results and recommendations in December 2002, identified a number of issues pertaining to the safe and economic usage of aircraft operating in the firebombing role. To address these issues, a number of operators, regulatory and customer agencies in the United States and Canada have commenced initiatives to characterize the loads to which firebombing aircraft are subjected, develop a rational and cost-effective basis for the continued safe and economic operation of the current firebombing fleet and develop a management plan which will ensure the transition of the fleet to more modern aircraft over the next decade.

This paper summarizes the efforts undertaken to respond to the recommendations of the Blue Ribbon Commission to date, and outlines the rationale behind an initiative that is being considered to ensure the ongoing availability and safe and economic operation of the North American firebombing fleet over the next several years.

The Firebombing Environment

Aircraft operating in the firebombing role general spend a large proportion of their time operating at altitudes below 762 m (2,500 feet) Above Ground Level (AGL). This environment is very different from the environment associated with the higher altitude transport/cargo role for which many of the current firebombing aircraft were designed. Any aircraft operating below 762 m (2,500 feet) is typically subjected to a much higher frequency of gusts than a similar aircraft operating at higher altitudes. Similarly, aircraft operating at these altitudes tend also to be subjected to a much higher frequency of manoeuvre loads as pilot input is applied to counteract the gusts and/or facilitate terrain avoidance. For firebombing aircraft the severity of the low-level environment is further exacerbated by the presence of the fire itself and difficult and varied terrain in which they are often required to operate.

Typical North American Firebombing Flight Profiles

North American large airtanker operations are generally coordinated by smaller lead aircraft who "lead" the airtankers to the location around the perimeter of the fire to where the retardant is to be dropped in an attempt to establish a fire break that will retard the fire. Generally, the airtankers are located at an airfield that is relatively close to the fire to minimize the time between drops. Initial transit to the fire is usually under 762 m (2,500 feet) to avoid the need and associated time loss associated with continuous climbs to and descent from higher altitudes. Upon reaching the fire the airtankers will join a circuit established by the lead aircraft in the immediate vicinity of the fire at an approximate altitude of 305 m (1000 feet) AGL. Once requested by the lead aircraft to commence a drop, the aircraft will descend to pass over the fire at an altitude of either 46 m (150 feet) AGL above level terrain or at a constant height of 46 m (150 feet) parallel to sloping terrain. Drop speeds are of the order of 200 – 240 km/h (110 – 130 knots). Typically 50% flap with a higher engine power setting is used to maintain the required drop speed over the drop zone. This provides access to immediate post-drop increase in thrust as the flaps are retracted immediately following the drop. Depending on the terrain varying degrees of pull-up and turns are pulled post drop in order to exit the immediate fire zone. Large airtankers will typically make two passes over a fire, dropping 50% of their total retardant capacity during each pass, before returning to the airfield to acquire more retardant. Depending on the retardant capacity of the airtanker each pass results in an instantaneous reduction in aircraft weight of the order of 4,540 – 6800 kg (10,000 – 15,000 lbs).

The Loads Experienced by the Aircraft

As noted by the Blue Ribbon Commission, there is very limited information available that quantifies the actual loads to which the large airtankers are subjected. What little information there is suggests that while these aircraft are subject to some quite high g-loads, any deterioration in structural integrity that may occur can be more often attributed to the cumulative effect of cyclic load (fatigue) excursions than any one large load excursion. Furthermore, preliminary analysis of the cyclic load excursions suggests that by far the greatest contributor to overall fatigue life consumption can be attributed to the large number of low-level cycles to which these aircraft are subjected as a result of the increased gust and manoeuvre frequencies encountered while continuously operating in a low-level environment.

Recent Actions Implemented

To evaluate how the health status of the current large air tanker fleet, a number of actions have been implemented:

1. A baseline inspection program of all airtankers contracted by the USDA/FS was undertaken by the U.S. Sandia National Laboratories (SNL) during Winter 2002/Spring 2003 to ascertain the current structural health status of each aircraft; and

2. The FAA has implemented a structural health monitoring system on one firebombing aircraft and the USDA/FS and SNL a program on three firebombing aircraft for the 2003 fire season with the aim of quantifying the actual loads to which aircraft are subjected in the firebombing environment. The data obtained will be compared to the loads to which the aircraft were originally designed so that the severity of the firebombing role can be assessed and a rational method of ensuring their continued safe and economic operation can be developed. It is hoped that up to twenty aircraft may be instrumented for the 2004 fire season and that the remaining fleet will be equipped with structural health monitoring systems over the next four or five years.

Longer Term Objectives

Although chronologically aging, many of the U.S Firebombing fleet have accumulated a relatively small number of conventional flying hours. However, the fact that many of these hours have been accumulated in an extremely aggressive environment for which they were not designed, pushes them into an area where they are subject to many of the challenges associated with aging aircraft. In the longer term the aircraft will need to be replaced. Unfortunately, budgetary and other constraints suggest that this process will not be instantaneous and that realistically many of the current fleet will have to remain operational for somewhere between five and ten years. Therefore, it will be necessary to manage the existing fleet through monitoring on an ongoing basis to assess the impact of the firebombing environment on the safe and economic operation of these aircraft. Additionally it is also proposed to use the data that is collected to develop a firebombing spectrum that can be used both to evaluate the suitability of potential replacement aircraft for firebombing before the expense of aircraft conversion is incurred and to define appropriate regulatory, inspection and maintenance procedures that will ensure the ongoing safe and economic operation of firebombing aircraft for many years to come.

Acknowledgements

The authors would like to acknowledge the support and sponsorship of this work by the Federal Aviation Administration and USDA/FS. In particular the contributions of Messrs. John Howford (FAA), Tom DeFiore (FAA), Ron Livingston (USDA/FS) and Tony Kern (USDA/FS) have been greatly appreciated. The considerable help and support provided by a number of firebombing operators should also be acknowledged. In particular the significant contributions of Mr. Norman Stubbs of TBM and Mr. Fritz Wester of International Air Response are gratefully acknowledged.

NOTES:

Improving Aerial Operations Safety

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Introduction/Objective

In the season of 1996, the Ministry of Natural Resources introduced a reporting system for documenting incidents, or those occurrences which were not captured through any other documentation process (i.e. accident reporting). Intent of this system was through capture of data, to identify trends or items which could potentially lead to a injury or fatality, and introduce changes to operational practices or procedures to avoid serious injuries or fatalities.

Data collected from aerial bombing operations indicated a high percentage chance of incident occurance. Although aerial bombing operations is recognized as a hazardous and dangerous operation, various internal processes and procedures were already in place to address known safety concerns. Incident report submissions received in initial year reported potential deficiencies in existing processes and procedures.

Intent of this presentation is to show what the Incident Reporting System identified to the aerial operations of the MNR, how and what was done to improve safety in aerial operations program, and results/ benefits that have improved the aerial operations program delivery in the MNR.

Approach

As a direct result of fixed wing bombing operations, incident reports were received in areas involving air to air, and air to ground communications; ground personnel in identified drop zone areas; air space management concerns; and interagency responses. To eliminate or reduce the types of incidents being reported, a method to refresh, and reinforce safety aspects, was required. A process would require to be identified that would develop, implement and maintain a cost and delivery effective method for safety messages. The messages and means of delivery would need to be tailored to meet internal and external agency involvement in aerial operations response.

Logistical obstacles hampered providing an effective method to deliver pertinent and required safety information. These included strategy/approach, staffing shortage of AAO's, funding availability, timely delivery of training to staff, consistent message across Ontario, and interagency response training needs.

A strategy and approach was developed which laid out basis for development of product. Product was to:

a) serve as a refresher for all Ranger crew personnel, and was not meant to add additional material not covered or taught in any other courses. It was acceptable that reference be made to existing procedures.
b) package was to be developed in a way that allowed non air attack personnel to use and deliver the package content for local Ranger Crew spring training purposes
c) package was to be developed so that fire personnel could utilize certain sections for delivery to outside agencies (i.e. Municipal Fire Departments)
d) package was to be provincial in nature

One of the initial steps within the product development process was to clearly identify the main areas which data showed a large percentage of occurance, and analyze potential areas which contributed to occurance. Initial data indicated approximately 10 areas were required to be included in product, and a Safety/Refresher CD focussing on these 10 areas was produced.

Training

Train the Trainer sessions were held, and CD packages delivered to the Trainers. Trainers were then tasked with delivery at respective locations for delivery at spring training sessions. Where possible, a Regional Air Attack Officer attended or delivered safety refresher sessions. To facilitate bomber group involvement/participation, pilots were invited to attend delivery sessions.

Responses from personnel receiving refresher were positive, with feedback received used for additional fine-tuning of product. Updated CD's were distributed for upcoming spring training season.

Portions of CD have been, and continue to be utilized for training purposes for municipal fire departments. Air Attack Officers and Fire Management Technicians have completed delivery of these training sessions.

Results

The development of a CD meeting the strategy and approach has paid dividends to safety in the aerial operations program. Dividends have been obtained in a noticeable reduction in incident report submission, as well as a low maintenance safety message delivery product.

Year	Initial Attack Missions	Support Missions	Incident Reports Submitted	Percent Chance of Occurrence
1996	64	6	6	8.6
1997	184	10	5	2.6
1998	321	27	11	3.1
1999	116	18	2	1.5
2000	78	3	1	1.2
2001	288	35	11	3.4
2002	95	12	1	0.9

From initial 10 areas, the safety refresher CD has evolved over the years to the point now where it focuses on key main safety areas of:

- Roles/responsibilities of AAO
- Communication
- Radio procedures
- Air/ground Procedures
- Air Space Management
- Interagency response
- Feedback

Numerous benefits have been realized from the initial product delivery, to present day. These benefits can be grouped into the three separate categories of safety, cost, and procedural. These benefits include:

1) increased awareness of incident reporting system which has resulted in a timely notification of occurance of incidents
2) reduced number of incidents involving ground forces
3) interaction between AAO's and field staff
4) increased knowledge of field staff of role of AAO
5) use of CD for non MNR Fire staff training (municipal), and not having to produce and maintain an additional training tool
6) increased awareness of interagency response forces
7) consistent provincial message delivery to all staff receiving training
8) additional material added to existing training course for Fire Ranger crews
9) improvements and additions to Standard Operating Procedures for Air Attack Officers and Initial Attack Fire Bosses
10) additions to short and long term hire helicopter briefing books
11) increased feedback from ground forces.

Conclusion

Statistical data indicates that the production and utilization of the Safety/Refresher CD has had a significant impact on reduction of incident submission in the aerial operations field. Increased fire line staff knowledge of aerial operations is reflected in statistics. Seven years of aerial operations bombing incident data has shown a initial drop in percent chance of occurance, followed by overall consistent low percentage chance of occurance.

NOTES:

Knowledge Management in the Wildland Fire Community

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The new, interagency Wildland Fire Lessons Learned Center is helping entities throughout the United States' wildland fire community become "Learning Organizations."

"A learning organization is an organization skilled in creating, acquiring, interpreting, transferring, and retaining knowledge, and at purposefully modifying its behavior to reflect new knowledge and insights."

Think about your own organization. Does your organization have a defined learning agenda, avoid repeated mistakes, capture critical knowledge before key people leave, and act on what it knows? Is your organization open to discordant information? These questions perform litmus tests for any organization wanting to know if they might be qualified to be called learning organizations. Specific practices and processes are also required, but the absence of these traits certainly raises serious doubts. (Garvin 2000)

Decision-makers affect the security and well being of firefighters on the fireline. Apprentice, journeyman and master firefighters continually need to make better-informed, knowledgeable and wiser decisions. "On-demand access" to knowledge, or at least "just-in-time," is a key concept. Proactive information transfer through networks of people to instill and retain the specific practices and processes that are required to ensure successful implementation is the second key.

Approach

According to a US Forest Service report from 2001, funding research into strategic, interagency knowledge sharing is an important aspect of the National Fire Plan: "Forest Service researchers and their cooperators are working hard to answer questions, including the following: "How can firefighters more fully understand the consequences of firefighting strategies and use this information to make better decisions on the fireline?" The National Fire Plan FY 2002 Performance Report describes the Wildland Fire Lessons Learned Center (Center) as one of its major accomplishments in training development. The report describes the Center as "a forum for firefighters at all levels to share successes and best practices evolving out of challenges experienced on actual incidents. They also can make suggestions to improve the Wildland fire training curriculum, and bring forward unresolved issues for broader review and input." The overall mission of the Center is summarized in these four objectives; (1) improve performance, safety, and efficiency (2) improve organizational learning (3) share knowledge (4) and promote organizational change.

Providing an effective way to identify, preserve, and distribute the knowledge that already exists in the fire management community is an important step toward all four of these objectives. The body of research into organizational effectiveness that focuses on this process uses the term Knowledge Management (KM). An article from a 1998 *Knowledge Management* journal defines KM as "the formal management of knowledge for facilitating creation, access, and reuse of knowledge, typically using advanced technology." (O'Leary 1998)

While technology plays an important role in organizational KM, it is not – and should not be – the only aspect to receive attention in a new KM development effort. Equally important is the process of identifying and describing the knowledge assets held by the organization, at both individual and organizational levels. A successful program to develop a Knowledge Management System (KMS) must take a hybrid approach, one that involves both people and technology. The Lessons Learned Center's strategy to put the wildland fire community to work as a learning organization involves two simultaneous efforts: (1) In the short-term create a successful KMS prototype using a pilot project with the prescribed fire Community of Practice (CoP) in fuels reduction benefiting the wildland/urban interface in a single region. Continue this effort and create a successful KMS using additional pilot projects with CoP's in fuels reduction, fire use and suppression in multiple regions. (2) Improve the transfer and retention of information through CoP networks about: collecting intelligence, benchmarking, how to examine past experiences and learn from them, how to experiment with new knowledge applications, how to transfer knowledge through multiple venues, and how to do CoP problem solving in a systematic way. These specific practices and processes are required to ensure successful implementation.

One critical learning tool that deserves special recognition is the After Action Review (AAR). The AAR process has been successfully institutionalized in many military and private sector organizations. The process has become standard operating procedure for capturing and disseminating critical organizational knowledge. (Garvin 2000) Like many other organizations, the prescribed fire and fire use community continually experiences learning that remain isolated, short-lived and trapped in the memories of individuals or separate units. The AAR begins a process that consolidates, distills and disseminates knowledge throughout the entire community of practice. At both organizational and individual levels, AARs will help hone prescribed fire and wildland fire use skills, knowledge and abilities.

Results and Discussion

Success is measurable across agencies by observing changes in two categories: (1) consistency of processes, and (2) a better safety record.

Current practices in Wildland fire have evolved over decades of participation by multiple agencies, with differing management practices, operation styles and wildfire environments. As the community-wide information exchange develops and lessons are learned, "best practices" should emerge. Best practice development models include the need for an objective and accurate understanding of knowledge gained or attitudes or beliefs changed due to participation in a program. The outcomes methodology, frequently implemented in the form of pre- and post-program surveys, not only demonstrates and documents a program's effectiveness but can be used to measure the degree to which different subgroups of the target population have pre-existing knowledge and the consistency of that knowledge. Employed in this way, the outcomes measurement approach can serve multiple aims: examining the pre-existing similarities and differences between agency and regional subpopulations; measuring the impact of the new program on the knowledge and beliefs of those disparate subgroups; and providing a developmental and longitudinal understanding of any changes in the consistency of adoption and penetration of the emerging best practices into the subgroups and overall target population.

As fire management and suppression practices become more standardized, safety issues should become easier to manage. When safety issues arise in the current environment, it is not always clear what practices were being followed, or whether the practices were a factor in the safety incident. This not only makes the investigation process more difficult, but also makes it difficult to understand how the issue could have been avoided or improved through a change in practice. When "best practices" become known, teams that follow them will have a better understanding of what was going on when safety issues arise, and should therefore have more control over improving their safety records.

An outcome measurement methodology can make two primary contributions in this area. In the short term, an incident safety/consistency-with-best-practice survey can be used to gather structured information from the crews and management teams *at the time and place* of the fire use or suppression incidents themselves, capturing subtle details of the experience that will fade as time progresses. This standardization of incident data collection and understanding can both be used to gauge consistency of best practice application and to make improvements to them based on factual data.

A longer-term view of outcome measurement and safety can be gleaned from a combination of the incident surveys mentioned above and archival, or institutional, performance records. In the long view, the implementation of best practices should have an impact not only on knowledge, beliefs and attitudes, but on actual safety measures, such as a reduction in the number and severity of incidents. As the Center knowledge base coalesces and begins to penetrate to the level of the line fire fighters, changes in the safety record of subpopulations who receive and implement the new best practices (as measured by the short term outcome measurement) should be identifiable in the more traditional safety performance measures.

Decision support made available in prescribed fire and fire use will be expanded to create a successful KMS for the entire wildland fire community in subsequent years. Using additional pilot projects with CoP's in fuels reduction, fire use and suppression, the prototype KMS will continually evolve into a dynamic resource center. Implementation of specific practices and processes through CoP networks on: collecting intelligence, benchmarking, how to examine past experiences and learn from them, how to experiment with new knowledge applications, how to transfer knowledge through multiple venues, and how to do CoP problem solving in a systematic way will ensure successful and sustainable learning organizations.

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NOTES:

Predicting Spatially Explicit Burn Probabilities Across Forest Landscapes Under Extreme Weather Conditions

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Introduction

Fire managers need to implement a variety of pre-suppression measures across forested landscapes to achieve their objectives. Such measures may include the modification of fuel complexes, the imposition of spatially explicit land use restrictions and other prevention measures and the deployment of fire suppression resources. Maps that illustrate how the annual predicted burn probability (BP) will vary across the landscape given the fire environment and a fire management strategy can and should be used for spatial risk management planning. The BP under extreme weather conditions is of special interest to such managers because most fire damage occurs in years during which extreme weather conditions persist over long periods of time. In this paper we describe a burn probability mapping methodology and how it was applied to predict BP under extreme weather conditions in a forest management unit in northeastern Ontario, Canada.

Method

The features of the landscape were described in a spatial raster GIS coverage with equal sized cells. Each cell has attributes that describe its elevation, slope, aspect, fuel type, historical fire ignition activity and initial attack response time. The Canadian Fire Behaviour Prediction (FBP) system was used to classify fuel types for each cell (Hirsch 1996). We calculated the BP of each cell by simulating the ignition of fires, the ability of initial attack forces to contain them, and the growth of escaped fires. The model identifies which cells were burned by each simulated fire and the simulation is repeated for a sample size of N years or iterations. Suppose n_i is the number of times cell *i* is burned during those N simulated years. Then B_i, the probability that cell *i* will burn next year is

$$B_i = \underset{N \to \infty}{Lim} \frac{n_i}{N} \quad [1]$$

All fires were classified as belonging to one of six categories: spring lightning-caused fires, spring people-caused fires, summer lightning-caused fires, summer people-caused fires, fall lightning-caused fires and fall people-caused fires. The probability distribution of the number of fires that occur in each class each year is assumed to be Poisson with a mean equal to that observed in the study area in the recent past (Cui et al. 2003).

Fires are allocated to specific cells within the study area based on the recently observed fire density of each cell (fires/km^2). The smoothed fire density of each cell was calculated by summing the number of fires that occurred within a 5 km radius of the centre of the cell and dividing by the area of that 5 km circle (Mitchell, 1999).

We modelled fire suppression effectiveness by using a simple level of fire protection parameter (LOP), the percent of fires controlled by the initial attack force. We assumed the LOP was determined by fire intensity at the start of initial attack and initial attack response time. Initial attack response time is the elapsed time from when a fire is first reported until the time the initial attack force begins suppression action. Fires that are controlled by the initial attack force burn only one cell and the growth of fires that escape initial attack is modelled using WILDFIRE (Todd 1999).

Results

We applied our burn probability mapping procedure to the 628,907 ha Romeo Malette Forest (RMF) in northeastern Ontario, Canada. The RMF is located within the Boreal Forest Region in an area of transition from the northern clay belt in the north to rolling glaciated uplands in the south (Anonymous 2000)

To minimize the impact of edge effects on our burn probability estimates we defined a 147.4 km by 137.6 km (2,028,224 hectares) rectangle to contain the RMF. The distances from the edges of the RMF to the corresponding edges of the larger rectangle are 8.9, 12.6, 22.9 and 20.5 km to the north, south, west and east, respectively.

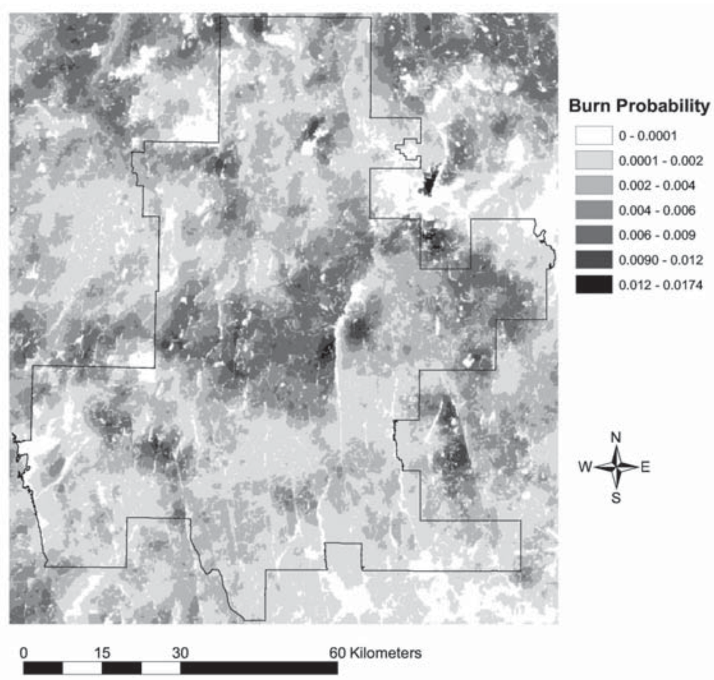

Figure 1. The burn probability map of the Romeo Malette Forest (the polygon) and surrounding area in northeastern Ontario, Canada under extreme weather conditions.

Fire records for the study area for the 1976-1999 period were obtained from the Ontario Ministry of Natural Resources (OMNR) and used to produce the ignition densities for lightning and people-caused fires. The average number of fires that occurred in the study area was 37.9 fires per year and the average annual burn fraction (BF) was 0.056%.

The weather records for 1991 were used to represent extreme weather conditions in the study area because they were the most extreme fire weather conditions observed over the 1976-1999 period. During that year there were 75 fires and 90.67% of them were controlled by the initial attack force at a final size less than 5 ha. The burn fraction (BF) was 0.25%. The BP map shown in Figure 1 is a prediction of what might happen during future extreme fire weather years similar to 1991.

Conclusion

The BP model takes into account the major factors that influence burn probability. The results include both the BP map and the BF's by fuel type. The model can be used:

1. To evaluate the effectiveness of fire suppression resources and policies. The LOP is influenced by both the ability to contain high intensity fires and the initial attack response time. The model can be used to assess the potential impact of increasing initial attack capabilities and/or decreasing response times.

2. It can also be used to help assess or optimize spatially explicit fire management strategies. For example, it can be used to assess the effect of fuel management or fuel breaks. If the BP model was linked with an optimizing model an optimal scheme of fuel break building or fuel treatment could be generated and evaluated.

3. It can be used to assess wildland urban interfaces (WUI) fire management strategies. (Sanchez Guisandez et al. 2002)

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NOTES:

High Resolution Surface Wind Simulations in Complex Terrain

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1. Introduction

It is generally accepted that wind speed and direction can be the dominant factor influencing fire spread and intensity; however, very few operational tools exist for obtaining such information. Spatial wind variability was a major factor in the fire behavior associated with recent fire incidents that resulted in firefighter entrapments and/or fatalities: South Canyon Fire 1994 (Butler et al, 1998), Thirtymile fire (2001), and Price Canyon Fire (2002).

Fire behavior predictions and forecasts are vital to tactical planning on wildland firefighting incidents. One major source of uncertainty in fire behavior predictions is spatial variation in the wind fields used in the fire models. In most cases wind data are limited to only a few specific locations, none of which may be actually near the fire location. Fire analysts, meteorologists and fire managers are left to general forecast information, guesswork and expert opinion for estimating spatial wind variability. These methods provide rough estimates of wind speed and direction at ridges and to a lesser extent in the valleys, but are subject to local knowledge and the skill level of the analyst.

Short-range meteorological forecasts and fire behavior calculations (e.g. 6-12 hrs) on large fires could greatly benefit from information on local winds over the entire terrain, at resolutions of 10 to 100 meters. The study described herein has two objectives: 1) develop a methodology for using commercially available software to produce high resolution surface wind maps and 2) quantify the utility of high resolution surface wind data on fire behavior predictions. This paper describes preliminary results of the modeling process applied to fire incidents in the Northern Rockies during the 2003 fire season.

While methods for resolving spatial variability in turbulent air-flows with associated heat source effects are well established in the engineering disciplines (Launder and Spaulding, 1974; Patankar, 1980; Barman, 2001), application of this technology to wildland fires has been limited. Lopes et al (2002) and Lopes (2003) describe a software system that combines high-resolution wind simulation with fire spread modeling. Two methods of producing wind fields are implemented: a linear model and a Navier-Stokes solver. Their study indicates that linear models can not accurately predict non-linear flows in steep terrain. They did not compare fire spread predictions from the FARSITE fire growth simulator with and without high resolution wind information.

This study combines digital elevation model data with general wind information using commercial CFD software to simulate surface wind speed and direction at discrete points on the terrain. Surface wind data from these simulations can be directly imported into FARSITE resulting in more accurate predictions of fire spread and intensity. Such data can dramatically affect the accuracy of fire perimeter predictions (Thomas and Vergari, 2002 and Graham, 2002).

During the months of August and September of 2003 more than 267 wind scenarios were simulated for over 26 fires or complexes in the Northern Rockies. Products provided to fire personnel included images of wind vectors over shaded topography and FARSITE simulations with spatially varying wind.

2. Wind Modeling Process

The process by which the gridded wind data are produced occurs in three steps. First detailed information about the terrain is obtained in the form of a digital elevation model (DEM). A computational grid of the terrain and atmosphere above the terrain is developed using the DEM as the bottom surface and a top boundary at 5 km. Cells near the ground surface are 10 to 100 meters tall. The horizontal was 90 m or larger. Cell counts ranged from 500,000 to 2.5 million cells.

A general wind flow is introduced by direction and speed and the conservation of mass and momentum equations are solved for every cell in the domain. Wind modeling for a specific fire typically consisted of simulating several different combinations of wind speeds and direction. The horizontal resolution of the data produced from the simulations was 90m at the surface over a 50 by 50km area. A typical solution (10^1 to 10^2 m resolution wind speed and direction) on a grid measuring 50 by 50 kilometers was achieved in 1-3 hours. Transfer of

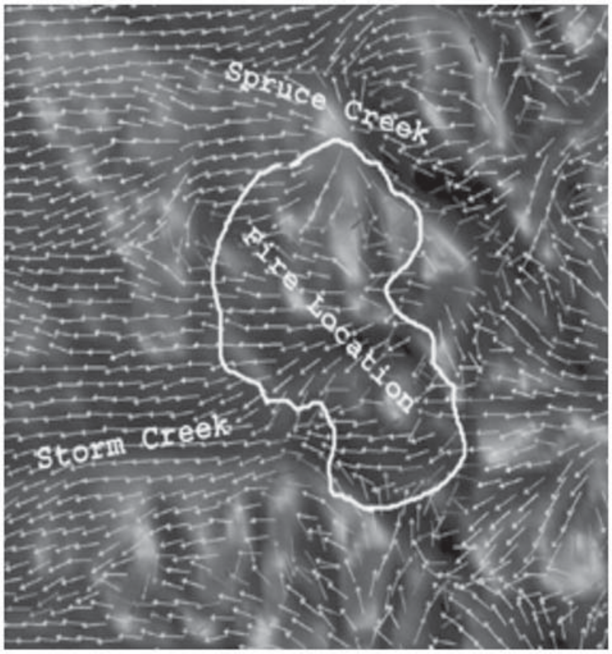

Figure 1—CFD simulation of 50-meter height wind velocities of the Price Canyon Fire area.

results from the wind simulations to fire managers and field personnel took many different forms, JPEG images proved useful, especially for field personnel (see figure 1). These images displayed the spatial variation of the wind speed and direction and were used to identify high/low wind speed areas along the fire perimeter and channeling and sheltering effects of the topography. The simulated winds can be geo-referenced to Digital Elevation Maps (DEM) meaning that vector output from the simulation could be overlayed on any GIS layer. The simulation process also produced input files for use by the FARSITE fire area simulator program. FARSITE modeling combined with the gridded wind has been shown to improve predictive accuracy of fire spread in all cases.

This technique was used on the Price Canyon Fire and the Hayman fires in 2002 and resulted in significant improvements in the capability of FARSITE to accurately predict fire growth. Figure 2 below presents a vector map of high resolution wind data prepared for the Price Canyon Fire Case Study (Thomas and Vergari, 2002). Figure 3 is a fire perimeter map based on FASITE simulations using local RAWS data for the wind input. The figure indicates that fire progression is overpredicted along the lower and right sides of the fire. Figure 3 presents the same image with the exception that high resolution surface winds derived from a CFD simulation were supplied to FARSITE. A comparison of figures 2 and 3 clearly indicates the dramatic improvement in FARSITE predictive accuracy using the gridded wind data.

These simulations assume a neutral stable atmosphere and do not take into account density driven flows (diurnal winds and fire induced winds). Neglecting these flows will introduce some error into the predicted winds. For diurnal winds this error will be greatest when the synoptic or upper air flows are low. However as the upper air wind speed increases the relative magnitude of this flow) will decrease.

1. Summary

Preliminary results suggest that the process described above can produce information useful to fire incident management teams, both to identify areas of potentially high intensity wind driven fire behavior and also areas that are sheltered from winds. Comparisons of FARSITE simulations with and without the high resolution surface wind indicate that in most cases there was improved accuracy of FARSITE fire growth projections. Future work will compare wind simulations against measured wind data with the aim of characterizing predictive uncertainty.

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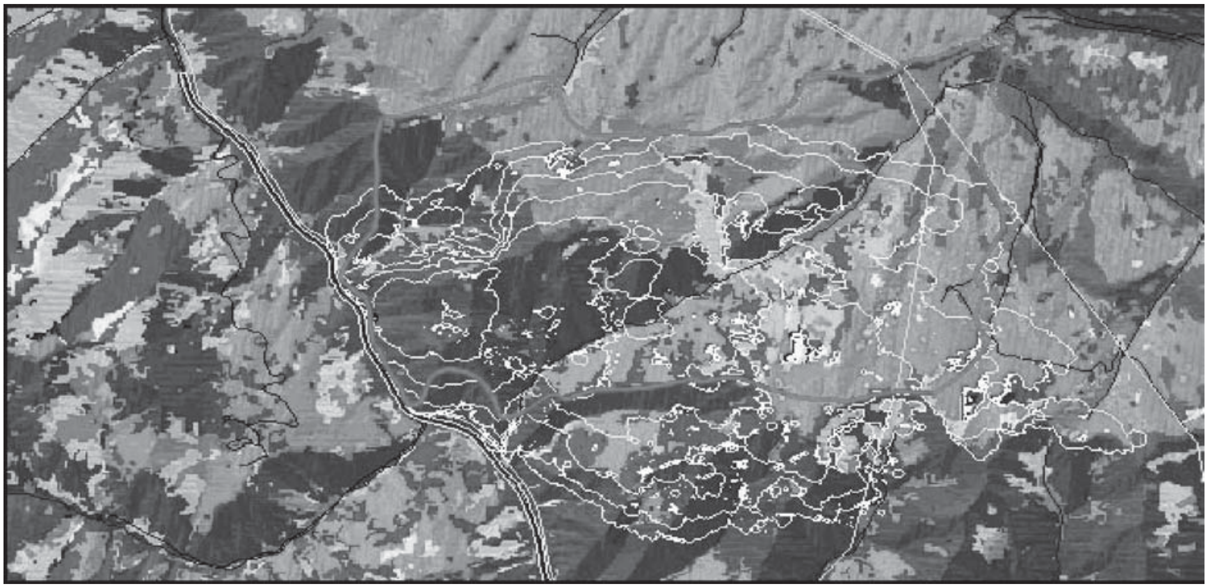

Figure 2—FARSITE simulation of the 2002 Price Canyon Fire using constant speed and direction winds.

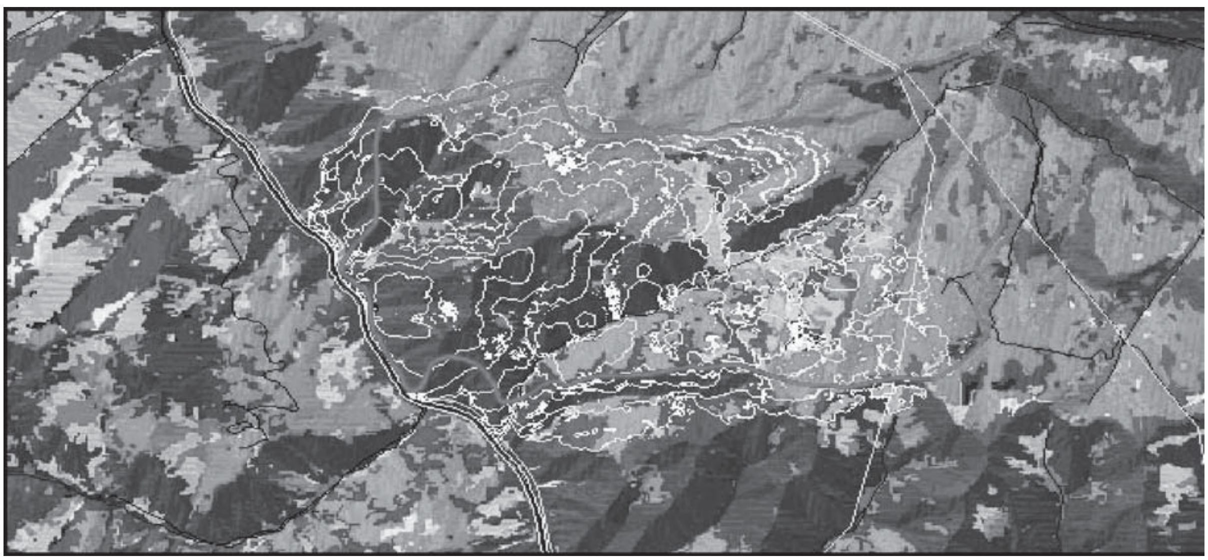

Figure 3—FARSITE simulation of the 2002 Price Canyon Fire using gridded winds produced by commercial CFD software.

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1. Acknowledgements

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NOTES:

A Low Cost Weather/Situation Monitor for Wildland Firefighter Safety

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1. Introduction

Wildland fire behavior is governed by fuels, topography and weather. Rapid changes in weather conditions can lead to fire break-outs and dangerous rates of fire spread that can imperil both firefighters and firefighting activities. Investigation of firefighter accidents often shows that rapid temperature rises along with an accompanying decrease in relative humidity, combined with shifting or rapidly varying winds (especially in fine fuels) to be major factors during entrapments. Fire weather on major incidents is transmitted by RAWS weather systems, but often these systems are deployed far away from actual firefighting operations, and the weather data transmitted may not be relevant to a particular crew or division operation. What is more desirable is an inexpensive, portable easily deployed version of the RAWS system that can be deployed at the division or crew level. For prescribed fires, such an inexpensive weather station could provide an added margin of control during ignition operations without the need for a weather observer to be tied to a belt weather station.

We have designed and implemented a lightweight, portable data recorder [Kremens (2003)] that can simultaneously measure 10 or more parameters associated with fire behavior. These units presently cost less than (US2003) $300, and we are working on even lower cost units (US2003) $100. A complete data recorder system configured as a weather station/fire data recorder consists of a weather vane/anemometer 'head', mounting mast, tripod, and data recorder/transmitter. (see Figure 1) The weight of the system is less than 8 kg, and two systems can easily be carried in a frame pack by a firefighter who is also carrying standard personal protective equipment, water and food. The units can be deployed in as little as 5 minutes, the majority of time being spent orienting and leveling the weather vane -anemometer sensing head.

2. Approach

The apparatus consists of two main components, a mast system and a data collection system. (see Figure 2). On the mast system are a wind speed and direction transducer, an infrared flux meter (to measure the radiant thermal flux from an approaching fire front) and a relative humidity/temperature sensor. The data collection system consists of a small waterproof enclosure housing electronics, battery and connectors for the mast sensors. Note that the device has the capability of accepting many more inputs than are currently deployed, if the need arises.

3. Preliminary results and discussion

The units were first deployed to monitor weather conditions within a fire front on a wildfire in Montana in July 2003 (Cooney Ridge Complex fire). This is an extreme application of the device, and we fully expected the weather sensing heads to be destroyed during fire front passage. The sensors were placed in position in front of an advancing wildfire front about 45 minutes before fire passage. The fuel bed consisted of small shrubs that had overgrown medium sized (7-8 cm diameter) logging slash, interspersed with tall grasses and sub-alpine fir and Englemann spruce of 15 - 30 cm DBH.

Two packages were positioned roughly perpendicular to the expected advancing front. Other sensors were also positioned to measure total flux (radiant + convective) and to observe the fire behavior. (flame height and rate of spread), The data acquisition unit was buried about 10 cm beneath the soil surface which provided sufficient insulation to protect the electronics from the fire. In this deployment, the data was stored in the data logger, although the data could just as easily have been forwarded to a remote site by radio using voice or audio frequency shift keying telegraphy.

In Figure 3 we show the response of the wind direction and speed and air temperature and relative humidity in the 10 minutes immediately preceding and following the passage of an active fire front. The fire was approaching from the north and was advancing upslope at about 50 m/hr. We can see that the wind direction, which before the fire was light and variable, begins to point directly into the fire before passage of the fire front. The temperature rises and relative humidity falls precipitously during the fire, but recovers to pre-fire levels in about 2 hours after the fire front has passed. This information would be invaluable to firefighters and especially to prescribed burn or backfiring crews to assist in prediction of fire behavior.

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Figure 1: A weather station/situation monitor deployed on a wildfire in Montana (Cooney Ridge Complex). The weather station is in the foreground; the other tripod mounts another experiment. The data logger is buried about 10 cm underground to protect it from the fire front.

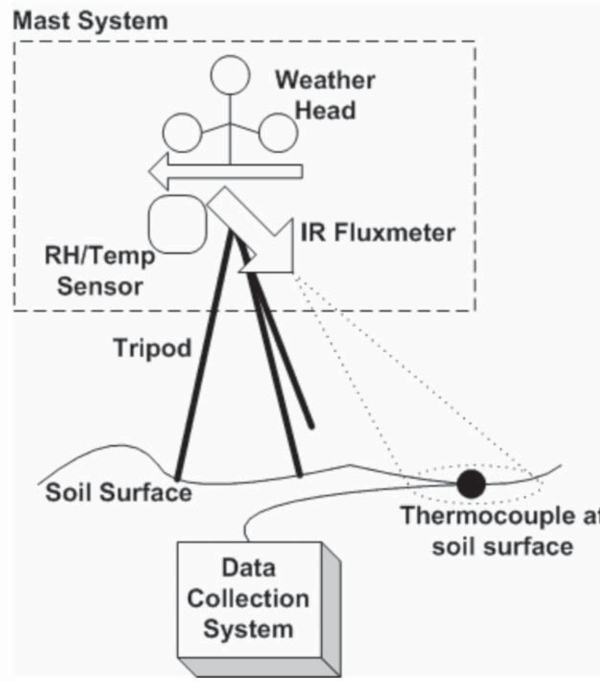
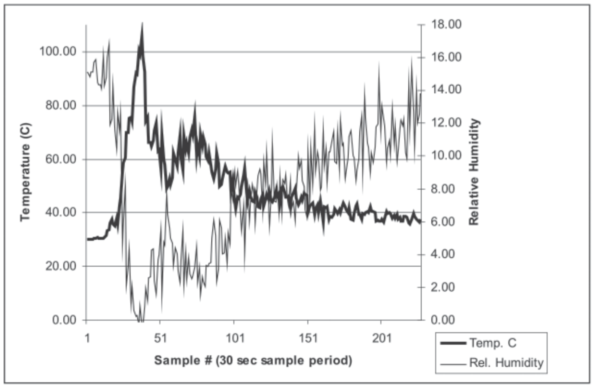


Figure 2 : An IR flux meter, relative humidity sensor, temperature sensor and wind vane (speed/direction) are mounted on a tripod about 2 m above the surface of the soil. ('mast package') The flux meter field-of-view is centered on a thermocouple that is in contact with the soil surface. The data from both sensors is logged as a time series by a buried 'data collection system'. Up to 3 additional sensor pairs and two additional thermocouples may be logged by a single logger.



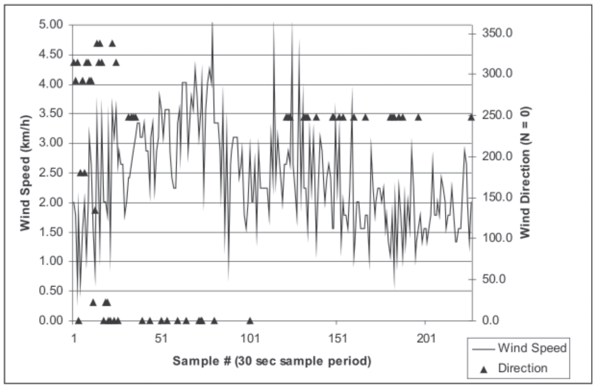


Figure 3: A plot of the relative humidity and air temperature (left) and wind speed and direction as a function of time (right as a function of time. The wind direction changed from west to directly toward the fire (0^{o}) during the time of fire passage. The fire front passed the mast system at about sample 40. Note the precipitous drop in relative humidity and increase in temperature during fire front passage.

NOTES:

Keeping it Fresh: Fire Behaviour Safety Messages During Extended Fire Situations

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Introduction

The new millennium has been characterized, in North America, by extended periods of extremely hazardous conditions. The Northern Rockies Region (Montana-Northern Idaho) in 2000 and southeastern British Columbia in 2003 are good examples of this. In the case of British Columbia, the fire hazard reached extreme levels by mid July and continued until cooler temperatures, higher humidities and showers began to reduce the hazard in mid September.

It is the overall responsibility of every Incident Commander to ensure that information is communicated to line staff to help ensure their safety. This is done through a combination of written forecasts and oral briefings as well as by observations by firefighters.

It is important that the severity of the situation is continually communicated in a way that keeps the attention of the line staff that need the information. This becomes more and more difficult as the situation continues. This paper outlines suggestions for keeping the message pertinent and ways to deliver the message to those who need it in a fashion that will get their attention.

Background

Every day on the fireline, firefighters are bombarded with information. On small fires, this information comes mostly from the fire in the form of observations that are made. Other information comes from other fire staff associated with the fire and communications with the management area responsible for the fire.

On larger fires however, in addition to the information noted above, the firefighter also may receive briefings, multi-page Incident Action Plans, broadcasted weather information or warnings and increased information from other firefighters.

It is extremely important that firefighters are provided the best information in a format that is brief, easy to understand and likely to be remembered. If the situation that is likely to cause extreme fire behaviour is short lived, i.e. on the order of one or two burning periods, it is fairly easy to produce and deliver a message that will make those involved take notice. However, in situations that continue on, with conditions worsening daily, it becomes more difficult to ensure that firefighters heed the message. This is likely due to at least two factors, the need to suppress the fire and the normalization of the extreme conditions.

During June of 2003 in north central Ontario, Wawa fire number 13 was continually active for ten days. Each day, the fire exhibited extreme fire behaviour, severely limiting any direct action that firefighters could take on the fire. As days passed, and the fire grew, there was an increasing desire to take action to halt the growth of the fire. Firefighters, by definition, fight fire. They take risks. They might wait one or two days for conditions to improve to the point where they can fight fire safely but they feel an increasing need to engage the fire. Even in a situation where the extreme fire behaviour predictions are verified by observed extreme fire behaviour, the safety message has to be continually “notched up” to ensure that firefighters are getting the message.

By the middle of July of 2003, conditions in southeastern British Columbia had reached a point where many locations would support extreme fire behaviour. The required Fire Behaviour Advisories were issued, warning firefighters and fire managers that problematic fire behaviour was possible. In some locations, these advisories continued almost daily for the next two months. Over time, extreme conditions such as Build Up Index values over 200 became commonplace. There is a very real danger that firefighters and fire managers continually exposed to these conditions become desensitized over time. This has been cited as a problem on incidents (Rosenkrance et al., 1994).

Firefighters coming in from other agencies were impressed by the conditions represented by the Fire Weather Index but as the resulting fire behaviour was not as extreme as they expected, the numbers lost their impact. This is not to say that the potential for extreme fire behaviour did not exist. In fact extreme fire behaviour did occur, and fairly frequently however, it was not a daily occurrence even though the Canadian Forest Fire Danger Rating System would produce potential for extreme fire behaviour on a daily basis.

Effective Communications

Fire behaviour and related safety information should be communicated in two ways. The information should be supplied in a written format and widely distributed and whenever possible, verbal briefings should be given to firefighters. In both cases, it is important to be brief and deliver only what is important to ensure the understanding and safety of the firefighters.

It is important to continually assess the key audience for the safety message. Wildland fire management has its own jargon. If the incident is entirely staffed with agency firefighters, references to specific fuel types by abbreviation will likely be acceptable. However, with a mix of agency firefighters, contract firefighters, forest industry equipment operators, crews from other agencies and possibly military staff, safety messages that include Danger Rating System abbreviations quickly lose their ability to communicate. In these instances, forest stands should be referenced by what they are, i.e. open, immature lodgepole pine. Fire behaviour safety messages should be presented so that the firefighter with the least amount of fire knowledge understands the risks and dangers for the day. After all, this is the person that is most likely to need to have the risks identified for them.

When it is possible to deliver the fire behaviour safety message at a briefing, the person who developed the safety message should be the one to present it. This person has the best understanding of the risks and cautions that are contained within. It is also very important that the person developing the safety message spend time in the field, observing conditions, fire behaviour and being seen by the firefighters on the line. This person will become more knowledgeable and more credible.

In the early stages of a fire, safety messages may be fairly generic because the specific conditions of and surrounding the fire have not yet been assessed. However, as time goes on, fire behaviour safety messages should become more pertinent to the specific fire environmental conditions that are affecting the fire.

A very important part of communicating fire behaviour information effectively is often overlooked. Every time a prediction or warning is issued, it should be commented on at the next briefing. If the prediction or event that was warned of occurs, it should be pointed out. If it does not, which seems to be more often the case, the reasons why should be determined and explained. In this way, both the person making the predictions/warnings and the firefighters receiving the briefing learns about the conditions that affect their fire. This completes the important cycle of analysis, prediction, validation through observation and reporting.

Safety messages should not be carried over verbatim from one day to the next, even if the burning periods share the same concerns. It is important to continually update and change safety messages. How many people would read a newspaper on the third day if it contained the same articles two days in a row?

The Role of the Fire Behaviour Analyst

One of the best ways to ensure safe operations on a fire is by making sure that expected fire behaviour is factored into the daily suppression tactics. A qualified Fire Behaviour Analyst would be an asset at dispatch locations and large fires as there is no one else at these locations that can devote their time to analyzing onsite conditions, predicting fire behaviour and then determining after the fact, through observations and further analysis, why there were differences between what was predicted and what actually occurred. Fire Behaviour Analysts are trained to analyse conditions, make predictions based on that analysis, observe fire behaviour and use those observations as part of the analysis for the next set of predictions. As well, the Fire Behaviour Analyst training emphasizes communicating fire behaviour and safety information to various audiences.

Conclusion

Effectively communicating fire behaviour and safety information is key to the success of every wildland fire incident. For information to be communicated effectively, it has to be brief, pertinent and understandable by all of the firefighters on the line. It becomes increasingly difficult to deliver a safety message as a situation continues and care must be taken to ensure that the message is continually updated and pertinent to the expected situation. Communicating why extreme fire behaviour did not occur is as important as predicting extreme fire behaviour. Fire Behaviour Analysts can aid in developing and communicating fire behaviour related safety messages.

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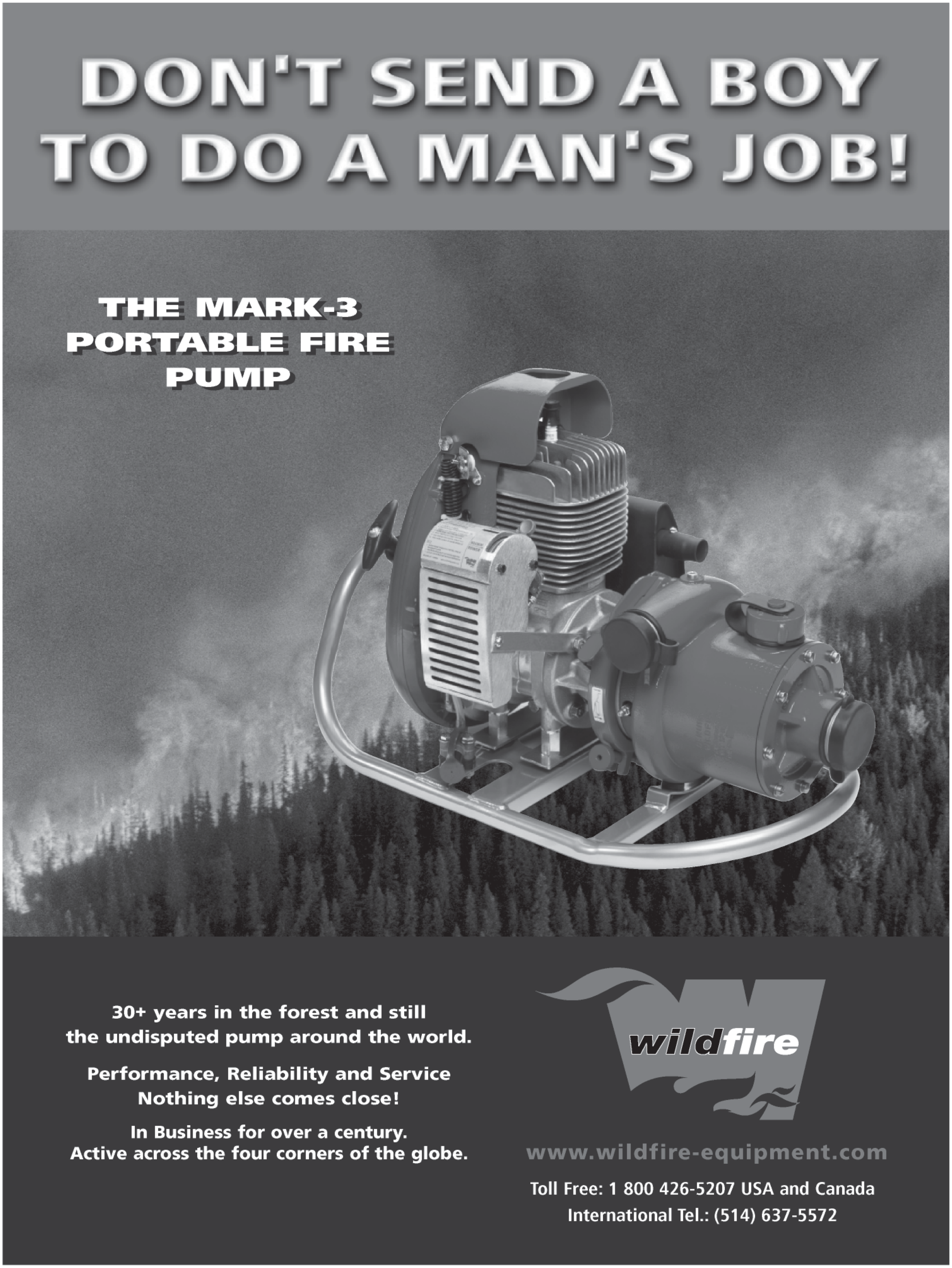
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Improved Pulaski and a Safer Hand Tool System & Strategic Positioning to Eliminate Loss in the Interface

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Improved Pulaski and a safer hand tool system:

The Pulaski is the most common traditional wildfire hand tool in North America. It was a versatile and good hand tool for early fire suppression efforts at the turn of the century, (around 1910) however, that was before every crew had chain saws, and the tool was used a lot more for cutting. Today it is used mostly for clearing and chinking fire line and mop-up. What it does is resign fire fighters to a bent over position of use. Most of their energy is wasted trying to use the 3 º" grub hoe blade to put in thousands of miles of fire line each fire season. Bent over fire fighters cannot see very will with a hard hat on. Pulaskis, shovels and short handled tools limit versatility, production a, and subject users to danger.

We advanced shovels and Pulaskis to form a new, safer, more versatile and productive hand tool system. Our replaceable blade Pulaski invented to make it a secondary tool attachment, (to be used only when needed). We made it a lighter, wider, longer, better balanced. It will last an entire career, and has the ability to use a green sapling as an emergency handle; if fire fighters get caught simply carrying just this attachment.

The Universal handle is the center of this variable hand tool system. Other attachments are primary tools designed to get fire fighters upright and comfortable. Mainly, an adjustable shovel, improved entrenching tool, a swatting tool, and a Asian Eye Hoe.

Strategic Positioning to eliminate loss in the Interface:

Defensible Space and traditional suppression methods work on low and medium intensity events.

Our future is more extreme wildfires. Terrorism is the other card. The possibility of coordinated, aerial, fire attacks, laid out in patterns of ignition perpendicular to strong regional winds, (by the tens of thousands of starts), and is something that simply must be addressed. We need an option to revert to fore extreme events.

Bolder and much more aggressive methods will indeed be safer, that the traditional thinning and pruning, followed by reactive water squirting. Massive evacuations, ragged and random efforts are not working. Loss is being tallied, but we tend to cling to methods that are familiar and only work on the easy fires.

Strategic positioning, inside circular cauldrons combined with new fire skills for both interface dwellers and fire fighters will secure society. Otherwise, the loss will keep growing. Fire agencies will continue to prove, that they do no know what they are doing, and have no clue, as to how to adapt to the new challenges.

Fire Management begins at the Critical Site and Moves outward into the landmass.

It will take more than just thinning and pruning the general land mass to fire proof our society. It will take an overall strategy É based on a change in thinking, training, and a new trust in the people, who live in the fuels.

To blame the entire wildfire problem on fuel loading reeks of ignorance. Thinning and pruning around homes and communities is a surface answer in the rush to address loss.

Fuel loading is certainly part of the problem, but all wild fuels burn. Grass and light fuels remain the main killers of humans and homes. Land management and new fire skills can be added to the thinning and pruning scenarios to actually eliminate all loss.

High drought does, combined with strong surface conditions create extreme firestorms, (that dwarf all available wildfire suppression resources) É Defensible space alone É can contribute to the speed at which critical sites will be destroyed. This becomes especially obvious, when fire managers evacuate threatened communities during fast approaching and powerful wildfires.

A Strategic Blueprint: Training, Prework, Trust and Cooperation Between Fire Fighters and Interface Dwellers. Fire agencies become leaders, helpers, and teachers, If they are confident enough to share skills, and responsibilities with those who live in the fuels.

The biggest shift in business is to get interface dwellers to assume the responsibility to prepare the ground around their home into a STRATEGIC CAULDRON. To instantly convert prepared ground into an instant "SAFETY HARBOR AREA".

This concept trains common people into land mangers; capable, experienced and confident enough to command events on their own holding. They become a trained resource, not just a growing problem. They must know when and how to parry wildfire. Make it pass, do not harm, when fire fighters can't stop it. Done right, the land is better after the fire passes; the large trees survive, and overall green-up is immediate.

Local fire departments, state and federal fire fighters must be trained to recognize "STRATEGIC, UNIVERSAL, BLUEPRINTS" and know how to instantly convert them into "SAFETY HARBOR AREAS"

Conclusions:

New wildfire hand tools, and circular, strategic positioning, combined with training fire fighters and interface dwellers will eliminate loss.

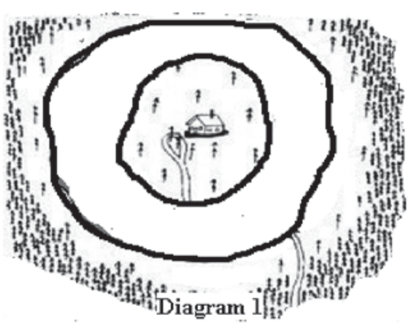

Diagram 1


Diagram 2

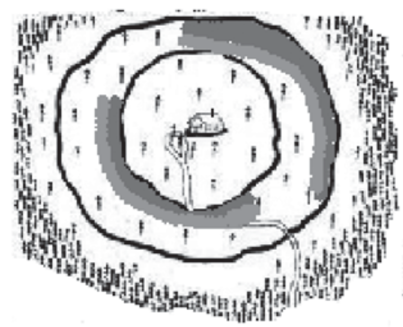
Diagram 3

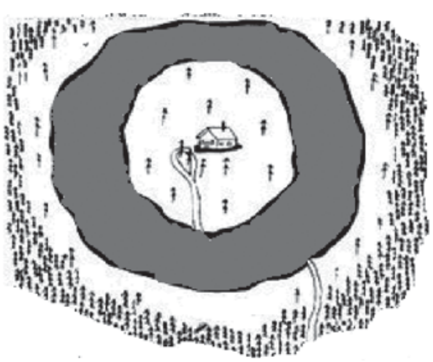
Diagram 4


Diagram 5

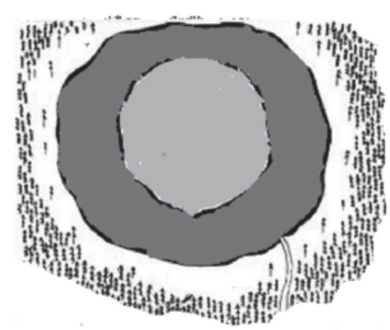
Diagram 6

Diagram 1. Shows a home standing in a treated landscape. Large fuels are pruned and thinned. They stand savanna like. Unable to be ignited by light fuels. Circular control lines separate light fuels from each other.

Diagram 2. Shows the semi circular pattern of ignitions laid via drip torch against control lines immediately down wind.

Diagram 3. Shows the natural black burning that takes place as the head fire goes into the control lines and goes out, but the fire burns slowly against the wind toward the circular control line up wind.

Diagram 4. Shows the outer black donut as all fuel inside the two outer control lines has been consumed.

Diagram 5. Shows the final 2 strips of fire laid against control lines. They then back burn towards control lines upwind.

Diagram 6. Shows the final "Safety Harbor Area" where the critical site stands in a large black spot devoid of light fuels giving plenty of space to endure the approaching wildfire.

Remember: The true beauty of circular control lines; is that Éthe wind is always blowing in the right direction for a very controlled burn off of light fuels. Keep your bites of fuel small, so they bump into control lines, and die. The remaining flames burn slowly against the wind to meet control lines up wind.

NOTES:

The Use of Leading Indicators to Measure the Performance of the Occupational Health and Safety System

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Introduction

The measurement of occupational health and safety success or failure has traditionally been demonstrated by the use of 'after the loss' type measurements such as injury frequency and severity. These measurements alone have been proven to be insufficient in evaluating the true state of occupational health and safety within an organization.

A low reported accident rate, even over a period of years, is no guarantee that risks are being effectively controlled, nor will it ensure the absence of injuries or ill health in the future. (Lindsay 1992)

In order to better evaluate organization effectiveness in the area of occupational health and safety management, additional, upstream measurements must be taken, and blended with the trailing indicators. These are referred to as leading indicators, which measure conditions or activities prior to an accident or incident occurring.

The intention of this presentation is to define and discuss leading indicators, focusing on using them to measure OHS system performance. The concepts may also be useful in reviewing the status of existing safety management systems (SMS), or in establishing a new SMS.

Approach

The purpose of this paper is to review the body of knowledge (or a portion thereof) relating to health and safety performance measurement, and extract content relevant to leading indicators. I am interested in examining the difference between the historical experience, which is typically expressed in trailing measurements, and focused primarily on the safety of the individual, versus the organizational model (Reason 1997) favoured by a number of leading researchers in this field, that uses leading indicators to measure safety management improvement (or deterioration) of the organization as a whole. The value of using leading indicators should be evaluated via being readily transferable or generalizable to any industry or process.

A literature review was conducted using databases at the Canadian Centre for Occupational Health and Safety, Institute for Work and Health, and references of related work. Once sufficient citations were obtained, 8 texts, 4 journal articles and 2 reports were selected for review. Additionally, interviews were conducted with three principals in health and safety management.

Discussion

The researchers and authors whose work is reviewed in this paper are noted in the table below, together with the type of method or strategy employed by them in studying the various aspects of their work. The application and findings column notes the type of workplace setting/activity that their research was used in, and the significant results or area that was most impacted by the use of leading indicators.

Researcher/Author	**Method/Strategy**	**Application/Findings**
Stewart	Model of Managing for Outstanding Safety	Workplace process; companies that manage OHS are more effective
Krause	Behaviour-based indicators	Use in judicious combination with accident frequency
Reason	Accident causation model	Incident investigation and proactive system checks; informed culture
Sefton	Developing leading indicators for benchmarking	Oil and gas exploration; process goes hand in hand with development of the company SMS and culture
Petersen	Linking safety performance measures coherently to business performance measures	Tying safety performance to bonuses and merit pay. Safety performance is rewarded and tied to compensation and/or operating budgets
Flin	Measurements of safety climate/employee survey	• management/supervision • safety system • risk • work pressure • competence

Conclusion

The literature references reviewed for this paper agree that the best way to determine the 'health' of the OHS system is by probing the system to check on the status of critical components. This is much like looking at the safety system as the 'patient', whereby we must identify the location and timing for measuring 'leading indicators', which must be captured by some mechanism. Once this data is obtained, we have an opportunity to proactively act on the information, and prevent 'illness' in the system. This is equivalent to early detection and intervention. By applying the principles discussed, using the tools existing and under development, together with pending research findings, leading indicators can be used to help organizations improve the way health and safety is perceived, operationalized, and managed. Many of the health and safety risk exposures in workplaces are of multi-factored origin, providing layers of opportunity for anticipation, detection, monitoring and control. Appropriate identification and action based on the use of leading indicators, will improve the performance of the OHS system.

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NOTES:

Fire Behaviour/Safety in Mountain Pine Beetle Killed Stands in British Columbia

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In 1994, 5000 ha in central British Columbia was detected to have a population of Mountain Pine Beetle, (area of red, dead pine trees). Attempts to eliminate the population by prescribed fire were unsuccessful and now the infested area covers millions of ha. of prime timber sale area and is going to continue to grow until a very cold winter (-40 C for 4 days) happens or they run out of pine.

This area of B.C. is predominately Lodgepole Pine, classified as a C3/C4 fuel complex. With the area changing from green to red to grey so does ignition potential, fire behaviour (rates of spread, head fire intensity's) and fire strategies and tactics. There has been no documented research in any of the above. In light of the lack of quantified data, our ground crews are initiating a summer long project trying to ascertain these changes and try to figure out how these changes will affect their safety, strategies and tactics on the fire line.

Questions that are being asked are many; will the fire move faster in the red trees vs. the green? (SAFETY), will our chance of fire increase with easier ignition due to the red needles/opened canopy?, will the fires burn hotter than in the green state and will that affect our ability for direct vs. indirect attack? (SAFETY), how sensitive is this new fuel complex to wind and rh changes? We DO NOT know the answers to any of these questions, it is all gut feeling.

The crews will be carrying out fuel loading, ground, surface, ladder and crown measurements along with Point Ignition Trials and 2 min test fires. We are hoping to find some answers but I don't think we will be able to get them all.

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