An Overview of Leopards: The Level of Protection Analysis System[1]

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Abstract

The Level of Protection Analysis System (LEOPARDS) allows the structured assessment of the outcomes and costs associated with alternative fire management policies, budgets, and suppression resource mixes. Its primary component is a deterministic, spatially conscious simulation model that emulates the daily fire suppression activities of a provincial fire management agency. Inputs for the model include historical fire weather and fire occurrence data, land-use objectives and operational rules, and infrastructure and suppression resource information. The model estimates physical outcomes (e.g., response time, number of escaped fires, area burned), fiscal results (e.g., fixed and variable costs), and resource utilization information. LEOPARDS has been used to address a number of strategic fire management issues in the province of Ontario and is being assessed for use in other parts of Canada.

Introduction

The Forest Fire Management Program of the Ontario Ministry of Natural Resources is responsible for providing forest fire management and protection to more than 85 million ha of the crown land in Ontario. Currently, Ontario annually spends an average of $85 million directly on fire management to respond to 1,761 fires, which burn 276,309 ha of forested land (less than 80,000 ha of which is intensively protected commercial forest).

Given the increasing complexity and cost of fire management, governments and fire managers are seeking techniques to systematically assess ways that fire management programs can efficiently reduce the detrimental social, economic, and biological impacts of forest fires. This has been called level of protection analysis (Martell and Boychuk 1997). In its broadest sense, level of protection refers to the amount of effort that an agency is willing to expend to respond to forest fires on the basis of its land and resource management objectives. This relationship can be depicted conceptually (equation 1), showing that the physical outcomes of forest fires (e.g., area burned, societal impact) are a function of the fire load (i.e., number, size, and intensity of fires) and suppression effort, which can be quantified in terms of dollars invested in fire suppression.

$$\frac{\text{fire load}}{\text{investment in fire suppression}} \Leftrightarrow \text{outcome} \qquad [1]$$

Hence, if a forested area is subjected to an increase in its fire load while the investment in suppression remains constant, the outcomes will be more severe. On the other hand, an increased investment in fire suppression will, in theory, reduce outcomes (e.g., area burned) if the fire load remains constant. To determine the economic, social, and/or environmental impact of forest fires, these physical outcomes must be translated into value change of the affected area and assessed within the context of the forest as a whole.

The Level of Protection Analysis System (LEOPARDS) is a decision analysis tool that can be used to predict the costs and impacts resulting from a set of fire management policies and budgets. It is primarily intended to address two types of questions:

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- Policy and Budget Alternatives-What are the costs and benefits associated with a change in fire protection zones or levels of protection? What are the costs and impacts of allowing more fires to burn with less suppression? What should be the size of the base and emergency fire fighting budgets? What is the potential impact of a budget reduction (or increase)? What types of outcomes could be expected if the budget provided for a significant increase in firefighters?
- Suppression Resource Alternatives-What is the most efficient mix of ground crews and airtankers that will enable the policy and budget objectives to be met? What are the benefits and costs of purchasing a new airtanker and what type of airtanker would be best for the local situation? Should there be more long-term helicopter contracts or should helicopters be hired on demand? What is the impact of closing or opening specific fire attack bases?

This paper provides a general overview of LEOPARDS by describing the structure and characteristics of the program, and it addresses strategic fire management questions in the province of Ontario and discusses development initiatives within Canada.

Structure

LEOPARDS is a computer-based decision support system that is similar in concept, but different in design, to other types of strategic fire management models, such as the National Fire Management Analysis System (USDA Forest Service 1985), the California Fire Economics System II (Fried and Gilless 1988), and the Aerial Delivery Firefighter Program (Wiitala 1998). The LEOPARDS model has evolved primarily from an initial attack model that was developed to evaluate airtanker requirements in Ontario in the early 1980's (Martell and others 1983, 1984). It also uses components of "LANIK" (Martell and others 1994), an extension of the original initial attack model produced in the early 1990's to allow more extensive analysis of level of protection issues. Active development and use of the current LEOPARDS model began in 1995 in Ontario in which the two earlier models were combined and extended into a new spatially conscious model.

LEOPARDS allows users to evaluate the effectiveness (physical results) and efficiency (fiscal results) of spatially explicit fire management objectives and suppression resource configurations. At the core of the program is a complex, deterministic initial attack simulation model that emulates the daily operational suppression activities of a provincial fire management agency *(fig. 1).* The simulation model requires three types of input (i.e., historical fire incidence and fire weather data, land-use objectives and operational rules, infrastructure and suppression resource information) and produces three forms of outputs (i.e., physical, fiscal, and resource utilization results). An important feature of LEOPARDS is that it accounts for the temporal queuing conflicts and spatial realities of forest fire suppression. In other words, it is sensitive to the problems that occur when there are multiple fire ignitions over a large area or a large number of fires in a small area in a short time period and only a limited number of suppression resources to attack them, which are situations that often lead to delays in initial attack and more fire escapes. Currently, the model does not simulate fire growth or suppression beyond the initial attack phase of suppression (i.e., until 10 a.m. the day following arrival); therefore, statistical techniques are used to estimate the total area burned based on the number of escaped fires.

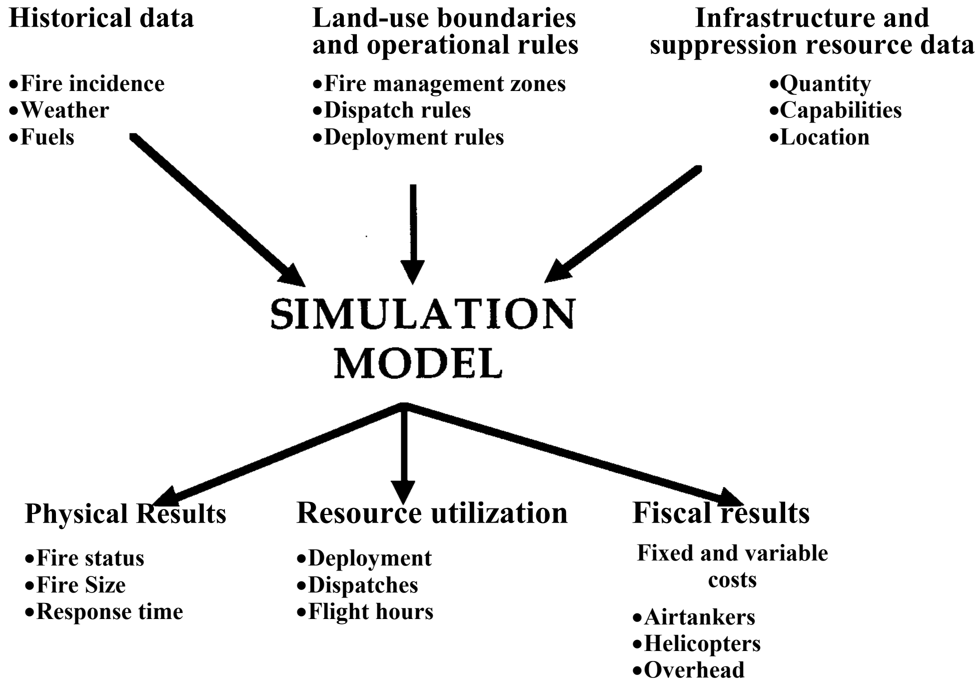

Figure 1
General structure of the LEOPARDS simulation model

Inputs

Several input files provide LEOPARDS spatial and non-spatial data. For instance, the province can be subdivided into any number of Fire Management Zones, each of which share common fire management strategies and general spatial characteristics (e.g., road access, distance to water). Each zone will have a specific set of initial attack dispatch rules that relate directly to the fire management policy for that zone. For example, in some parts of Ontario there are areas where fire is aggressively initial attacked because of the high values at risk (e.g., communities or valuable timber resources), and there are areas where fire is not attacked as aggressively because of lower values at risk or the view that fire can be beneficial.

Information in the Dispatch Rules defines the resources to be dispatched in each Fire Management Zone under different fire behavior conditions. These dispatch rules were derived through focus group sessions with experienced dispatchers. The focus group identified four criteria (rate of spread, fire size, flame length, and fuel type) upon which dispatch decisions are made. For each possible situation the group collectively identified the number of crews and airtankers they would dispatch and the desired response time objective given the fire management objectives within the area.

The Dynamic Deployment database file defines the type, location, operating cost, and capacity of each initial attack base. It also specifies the initial allotment of resources at each base at the start of the year as well as any constraints pertaining to resource deployment (e.g., a central base in a high value wildland-urban interface area might require at least one airtanker regardless of the fire danger conditions that exist in that area or elsewhere). Although LEOPARDS works through the fighting of fires on each day, this file tracks the movements and availability of resources from one day to the next.

Information about the capabilities and costs of various types of aircraft is contained in the Aircraft Attributes file. This includes firefighter transportation and water/ retardant dropping capability; aircraft cruising and working speed; mobilization, take-off, scouting, dropping and landing times; fixed and variable costs; and operating constraints (e.g., maximum wind speeds). Currently the model allows up to four types of aircraft (including helicopters) to be specified.

The Airtanker Drop data file contains data from drop pattern analyses of different aircraft (George and Blakely 1973, Stechishen and others 1982) that have been converted into fire line lengths of specific water depths. For example, a water drop from a CL-215 is able to create 226 feet (69 m) of line with a minimum water depth of 0.005 inches (0.002 cm), 220 feet (67 m) with a depth of 0.01 inches (0.003 cm), etc. (Australian Fire Authorities Council and Bombardier Inc. Canadair 1996). This type of data can be determined for both closed and open canopy fuels and is used in defining the effective line building rates of the airtankers.

The Historical Fire data file contains spatial and temporal information about each fire used in the simulation. Historical fire records provide the location, time, cause, discovery size, fuel type, and fire behavior characteristics of each fire. Spatially interpolated, diurnally adjusted fire weather is used with the fuel type information to model the growth of each fire using the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). This set of historical data is assumed to be indicative of what can be anticipated in the future; therefore, a relatively long historical data record (e.g., 20 years) is likely to be more representative of the range of possible conditions than a short record (e.g., 2-3 years).

The Simulation Parameters file defines a wide range of variables that control the simulation. It also allows the user to specify the value of certain variables (e.g., temporary helicopter costs, standard crew size) and to test the sensitivity of specific assumptions and variables within the model (e.g., crew and airtanker line building productivity, detection size).

Simulation Process

LEOPARDS simulates the activities conducted by a typical fire management organization on a daily basis and on each fire *(fig. 2)*. At the start of each new day a preparedness plan is implemented in which resources are deployed around the province. This deployment includes both aircraft and personnel and allows for the temporary hire and release of crews and helicopters as well as the inter-provincial sharing of airtankers.

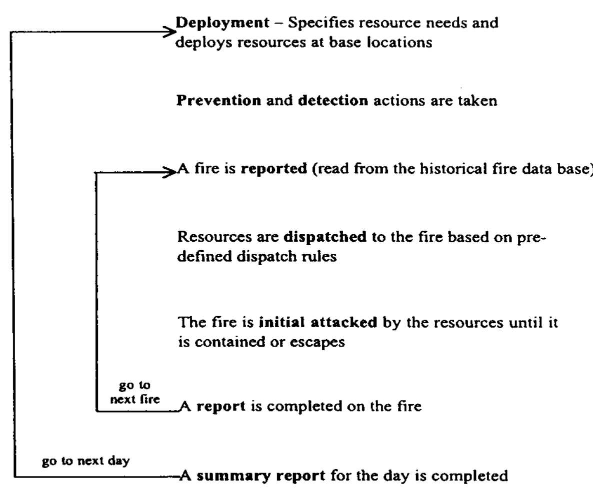

Figure 2
Simulation process of LEOPARDS.

Prevention and detection activities follow deployment. The model uses a simple screening process that acts upon the historical fire incidence database to eliminate a proportion of the human-caused ignitions and/or change the initial fire discovery size. The detection screen is a multiplier that affects all fires by the same proportion (e.g., a doubling of the detection size). The prevention screen can target specific causal agents, locations, and the time of year as necessary. Relationships between financial investments in detection or prevention and the resulting change in detection size or number of ignitions are defined by the user.

After the detection of a fire, the model reads key information from the historical fire incidence database and then begins tracking the growth of the fire on the basis of the interpolated, diurnally adjusted fire weather / danger data and the fuel type at the point of ignition. The next step is to dispatch resources based on the predefined dispatch rules. Because the historical fire data is read sequentially, the model actions fires in chronological order. Available resources are sorted by time-proximity to the fire location and those resources that can arrive at the fire first are dispatched and assigned to the fire.

Once resources arrive at the fire, suppression activities begin. Fireline construction and fire growth are modelled simultaneously using Quintilio and Anderson's (1976) initial attack containment model, which captures the interaction between these two processes. Initial attack continues until the requirements for fire containment are met (e.g., 80 percent of the fire perimeter is contained --- a user defined criteria) or the fire is determined to have escaped. If the fire is contained, resources are returned to the nearest base and become available for another dispatch. If necessary, airtankers will return to base before a fire is contained to abide by flight constraints (e.g., low fuel, night, daily flying time restrictions). Firefighters remain at the fire for at least the remainder of the day and, depending on the time at which containment occurs, may stay a second day to complete mop-up activities. Once a fire escapes initial attack, airtankers return to base but firefighters can be detained up to 3 days. The simulation model does not currently attempt to model suppression activities on escaped fires but does allow some "draw down" or reduction in initial attack resources if a fire escapes. It is assumed that after 3 days, sustained action suppression resources will be in place, allowing the initial attack crews to return to their activities.

After the completion of the initial attack phase of each fire, a report is produced and stored for future analysis. The model works through each fire for each day and then produces a daily activity summary. The model then moves on to the next day by returning to the deployment phase. This looping through each fire and each day continues until all the fires on all the days in the historical database have completed.

User Interface and Program Design

The simulation program is currently embedded within ArcView[4], a PC-based geographic information system (GIS). The GIS acts as a tabular, graphical, and spatial data input and analysis tool. The initial attack simulation model provides data to ArcView for analysis, or results can be ported to a statistical software program. The bulk of the simulation model is written in FORTRAN; however, more recently developed subroutines are written in C and LINDO.

Applications

LEOPARDS has been used extensively in the province of Ontario to help gain insights into a wide range of complex fire management problems. This is done by changing the model's inputs, running the simulation, and then examining the results within the context of the assumptions and limitations of the data and model. A few of the issues that have been addressed recently include: assessing the interaction of different fixed and variable budgets, identifying optimum levels of initial attack firefighters, comparison of fleet conversion of Canadair CL-215s, determining the benefits of using of ground foam, and changing the boundaries of Ontario's Fire Management Zones and altering the level of protection within those zones.

Relationship Between Fixed and Variable Suppression Costs

Theoretical models that relate fixed and variable fire suppression costs have existed for many years (Arnold 1949, Gorte and Gorte 1979, Sparhawk 1925). It is, however, difficult for a particular agency to thoroughly examine and quantify

[4]Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

this concept by using actual fire cost data because of the data's limited value range and changes in fire management polices and practices over time. These constraints can be overcome by using a simulation model like LEOPARDS. For instance, when the fixed (or presuppression) budget for the province of Ontario is increased, the variable costs decline *(fig. 3)*. For each simulation run, the amount of fixed funding for suppression resources (full-time firefighters, airtankers, helicopters, attack bases, detection and prevention) was increased over a range of $10 million to $25 million. Initial increases in fixed cost investments yielded a rapid reduction in the percentage of escaped fires, variable costs, and total costs. The total cost curve suggests that there is an optimum fixed resource level *(fig. 3)*; however, the "penalty" for minor departures is relatively small. For example in this scenario, there is little difference in the total cost even if the fixed budget varies from $13 million to $18 million. The total cost will also begin increasing when increases in fixed suppression expenditures have less impact on the percentage of escaped fires (e.g., simulation runs 15 to 23; *fig. 3*).

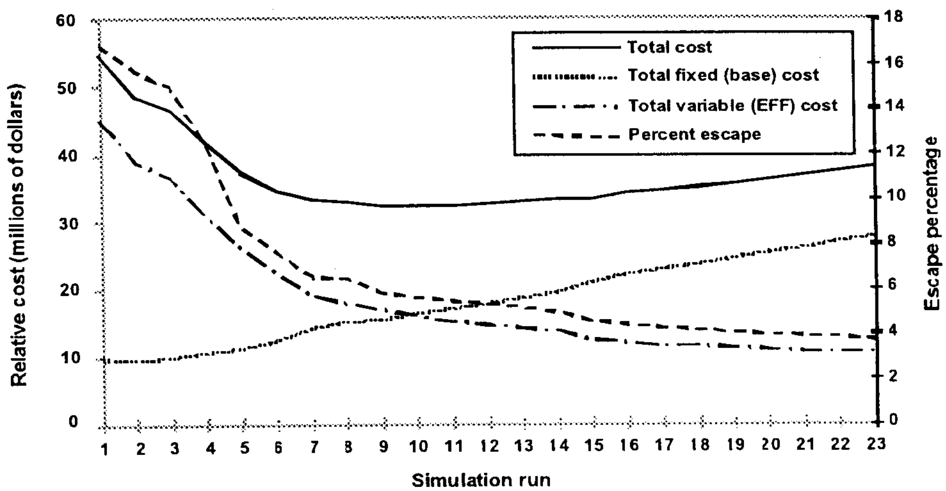

Figure 3
Relationship between fixed and variable spending; the percentage of escaped fires; and total fire management cost (generated from a series of LEOPARDS simulation runs, each one with progressively more suppression resources in a relatively proportionate balance).

Identifying the Optimum Number of Initial Attack Firefighters

A question frequently asked of and by fire managers in Ontario is "What is the optimum number of full-time initial attack firefighters for the province?" To address this question a series of simulation runs, each with a different number of firefighters, were made using LEOPARDS. The analysis was conducted based on the current attack base configuration, air attack resources (i.e., airtankers and air transport), and fire management zones and policies. Costs for seasonal and temporary out-of-province firefighters were provided. Constraints were placed on how fast temporary firefighters could be acquired, and it was assumed that they would be equally efficient at building fireline. For each scenario, the number of escaped fires was determined as well as the total fire management costs for the province. Given that LEOPARDS does not currently model sustained action fires, a statistical method based on historical information is used to determine the cost of an escaped fire, and this is incorporated into the total cost value derived for each scenario.

The model's results were determined for situations in which the number of firefighters in Ontario varied from 342 to 702 *(fig. 4)*. There was a local minima between 390 and 440 firefighters, but when the number of firefighters exceeded this local minima, the total cost dropped to the true minima of 470 to 540 firefighters. The true minima is flat because the cost of the additional firefighters is offset by the saving incurred from fewer escape fires. This flatness also suggests the model is relatively cost-insensitive to changes in the number of firefighters over this range.

This information would suggest that the optimum number of firefighters would be between 475 and 550 *(fig. 4)*, but there are other considerations that must be taken into account before reaching a final decision. For example, it is necessary to allow firefighters time off during the summer; this effectively multiplies the results by seven-fifths, increasing the optimum to 665 to 770 firefighters. It is also known that the current model does not incorporate uncertainty associated with fire occurrence and deployment; therefore, a buffer of firefighters (e.g., 40-60) should be added to the optimum.

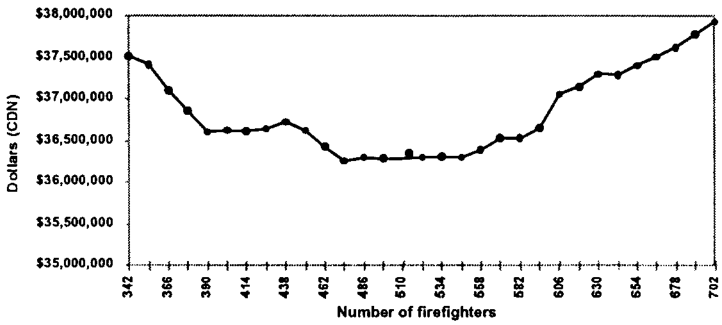

Figure 4
Total fire management costs for a series of LEOPARDS simulation runs with varying numbers of firefighters.

This analysis illustrates the importance of integrating the model results as they are produced with an understanding of the operating characteristics, assumptions, and limitations of the model. This analysis and subsequent interpretation was the basis for increasing the complement of initial attack firefighters in Ontario from 599 to 699 for the 1998 fire season with plans for a further increase to 750 firefighters in 1999.

Future Development

Although LEOPARDS has been used extensively and effectively in Ontario, work is continuing to further enhance and extend the model in two ways. First, procedures are being developed to include risk and uncertainty in the deployment component of the model so that it will more accurately reflect operational deployment activities and costs. Second, a new subroutine is being developed to extend LEOPARDS beyond the initial attack phase of fire suppression to include multi-day fire growth for escaped and non-actioned fires. This abstract simulation module will allow the assessment of alternative policies and strategies pertaining to large fires.

Nationally, LEOPARDS is being evaluated through the Canadian Forest Fire Centre (CIFFC) Fire Economics Working Group, to determine if the model can be adapted for use in other parts of Canada. This evaluation will identify modifications and additions that are necessary for the model to effectively reflect the varying forms for fire management policies and suppression activities present in different Canadian agencies. For example, in western Canada land-based retardant aircraft capable of making drops on multiple fires are commonly used, but this practice is not currently modelled in LEOPARDS. Modifications of this nature will require a re-assessment of the modelling procedures used in LEOPARDS and a re-engineering of the program to make it more versatile and adaptable.

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