A Spatial Analysis Approach to Forest Fire Preparedness

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Abstract

This paper describes how spatial analysis can be applied to forest fire preparedness planning. Using interpolation techniques, Canadian Forest Fire Weather Index (FWI) System inputs and outputs can be estimated between weather stations. When the interpolated FWI system outputs are used in conjunction with Canadian Forest Fire Behavior Prediction (FBP) System fuel types interpreted from forest inventories, the fire behavior potential can be evaluated spatially for the wildland protection area. Fire behavior potential maps such as forward rate-of-spread and crowning potential can be simulated using this approach. When potential fire size and initial attack policies are incorporated, an attack time objectives map is produced for the protection area. Resource deployment is evaluated by comparing fire control resource positioning with the attack time objectives map. The net product of this analysis is the coverage assessment map. This product classifies the forest on the basis of no coverage, coverage by one resource, or coverage by two or more resources.

Résumé

Ce document décrit comment l'analyse spaciale peut s'appliquer à la planification de la préparation de la défence contre les incendies. En utilisant des techniques d'interpolation, les intrants et extrants de l'indice Forêt-Météo Méthode Canadienne (IFM) peuvent être estimés entre les stations météorologiques. Lorsqu'on se sert conjointement des extrants interpolés provenant de la méthode IFM, avec les genres de combustibles de la méthode canadienne de la prévision du comportement des incendies, interputés à partir des inventaires de la forêt, le potentiel du compostement du feu peut être évalué en espace pour l'endroit de protection de la friche. En utilisant cette approche, des cartes du potentiel du comportement des incendies tels que le taux de vitesse avant et le potentiel de la cime peuvent être simulés. Lorsque la grandeur potentielle de l'incendie et les directives d'attaque initiale sont incorpories, une carte des objectifs de l'heure d'attaque est produite pour l'endroit de protection. Le deploiement des ressources est évalué en comparant le positionnement des ressources de contrôle de l'incendie avec la carte des objectifs de l'heure d'attaque. Le produit net de cette analyse est la carte de détermination de la couverture. Ce produit classifie la forêt sur une base d'aucune couverture, couverture par une ressource, ou couverture par deux ressources ou plus.

Introduction

Preparedness planning is the process of determining the fire control resource levels required to meet, or at least cope with, an anticipated fire situation. This planning is done by the fire manager, either during the morning or the previous evening. Using forecasted weather values to determine the relative fire danger for the next burning period, and a knowledge of wildland fuels and values-at-risk, the fire manager can make qualitative assessments of the resource levels and positioning required for the target period.

The purpose of this paper is to describe a quantitative approach that employs spatial analysis techniques for forest fire preparedness planning. The objective is to improve our presuppression deployment of fire control resources.

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Preparedness Planning in Canada

A number of fire management agencies in Canada have developed preparedness planning schemes in recent years. While these systems vary in complexity and approach, they all strive to meet the same objective of ensuring rapid and adequate initial attack. The Presuppression Preparedness System (PPRS) described by Gray and Janz (1985) outlines the initial attack scheme presently used by the Alberta Forest Service. The preparedness level for each forest is determined from tables using ranges in component values derive from the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). The preparedness, or man-up, level dictates the amount of fire suppression resources to be activated by the forest based on these predetermined fire danger ratings.

Within the forest, attack time objectives (or initial attack objectives as stated in this text) are determined using FWI system value ranges. The attack time objective defines a sphere of influence for fire suppression resources. The regional fire manager then deploys these resources at bases within the forest attempting to maximize their coverage or minimize their response time.

Since 1985, the PPRS has incorporated fire growth predictions using the Canadian Forest Fire Behavior Prediction (FBP) System (Lawson et al. 1985). The attack time objective has been revised to the growth time required for a hypothetical fire to reach 1.2 ha in the worst case fuel type (black spruce) under the given FWI conditions.

Though this system has been successful in reducing the number of campaign fires in Alberta, the authors recognize that an overmanning problem may exist. This situation stems from inadequate handling of spatial data - namely fuels, weather and terrain. Often, the worst case weather and fuel within a forest or initial attack zone is used to determine deployment requirements. A more detailed approach is generally beyond the limits of an operational office.

Intelligent File Management Information System

Recent developments have made the personal computer a practical tool for fire management. Larger storage and faster processing capability make the management and integration of large databases, such as forest inventories and weather, more feasible. With easy access to this information, a fire manager can analyze and support his decisions with site specific records and spatially interpreted data.

The Intelligent Fire Management Information System (IFMIS) is a microcomputer based software package under development at Forestry Canada's Northern Forest Centre (Lee 1989). IFMIS is a decision support system for use in forest fire preparedness planning and in the initial attack dispatching of fire suppression resources. Integrating mathematical modeling, geographical information systems, and expert systems, IFMIS aids the fire manager in the decision making process by conducting a more detailed approach to preparedness planning. This approach is presented in this paper.

Canadian Forest Fire Danger Rating System

IFMIS uses the Canadian Forest Fire Danger Rating (CFFDRS) System as a model to predict fire danger and fire behavior in Canada (Stocks et al. 1989). It has been in development for over twenty years and has proved quite successful in describing the fire environment. The CFFDRS is an integral component of IFMIS for its fire behavior modeling.

The CFFDRS consists of two subsystems: the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) and the Canadian Forest Fire Behavior Prediction (FBP) System (Lawson et al. 1985). The FWI system estimates forest moisture conditions with the input of daily weather. These inputs are: temperature, humidity, wind, and precipitation. The FBP system predicts fire behavior using FWI system outputs, FBP fuel type classifications, and terrain characteristics. Outputs from the FBP system are the forward rate-of-spread, the fire shape, size, and perimeter.

Interpolating Fire Weather

A problem faced when handling weather information is how to interpret values between stations. The standard approach used by meteorologists is to contour the information by eye. Computer systems for national weather services use objective analysis schemes to derive a spatial field. This is done by balancing observed data with dynamics relationships in the atmosphere, such as the geostrophic wind relation (Haltiner and Williams 1980). While the FWI system uses weather data as inputs, the output values are statistically based and do not lend themselves to objective analysis. As a result, alternative interpolation techniques must be used.

INTERPOLATION TECHNIQUES

The first interpolation technique that is intuitively obvious is a nearest neighbor approach. This technique interpolates the FWI output values at a given point as equal to those of the closest weather station. Though this technique has the merit of being easy to apply and understand, it has serious drawbacks. Spatially, this technique creates a patchwork of polygons known as Theissen polygons, which have no bearing on climatology or topography. Being a choropleth technique, each polygon has constant FWI values and at the boundaries, sharp discontinuities occur as values step up or down to the values in the neighboring polygon. Figure 1a illustrates a nearest neighbors analysis of the buildup index (BUI) for May 4, 1988. Theissen polygons are outlined. The BUI value within each polygon is constant and equal to the value at the weather station within the polygon.

The current interpolation technique used by most forestry agencies is cell assignment. Cell assignment is a choropleth technique that designates a region of influence for each weather station. All points within the region are assumed to have the same weather as the station. Cell assignment is a more reasonable technique as it allows for climatological and topographical considerations. For example, weather within a mountainous region would be best represented by a weather station within the region than one outside, even though the latter may be closer to some points within the region. But, like the nearest neighbor technique, cell assignment has the disadvantage of not creating a smooth value gradient between stations. Another disadvantage is the amount of time and expert knowledge required to designate effective assignment regions. Figure 1b shows a cell assignment analysis of the BUI for May 4, 1988. The forest has been divided into regions. Each region has an assigned weather station. The BUI value of the region is constant and equal to the value at the assigned weather station.

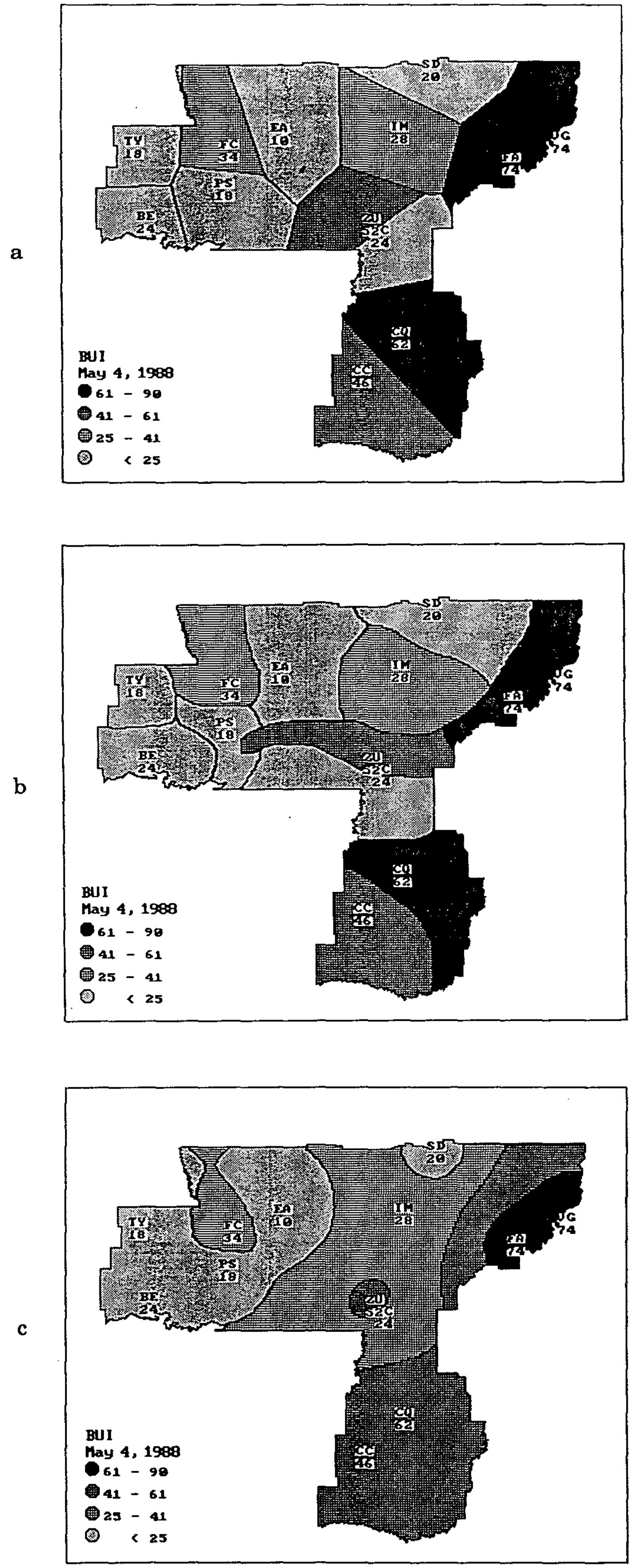

FIG. 1. Schematics of how (a) nearest neighbor, (b) cell assignment, and (c) weighted moving averages analysis techniques for the Buildup Index, as derived from the Canadian Forest Fire Weather Index (FWI) System, for May 4, 1988. The BUI values for each station are placed under their two letter identifier.

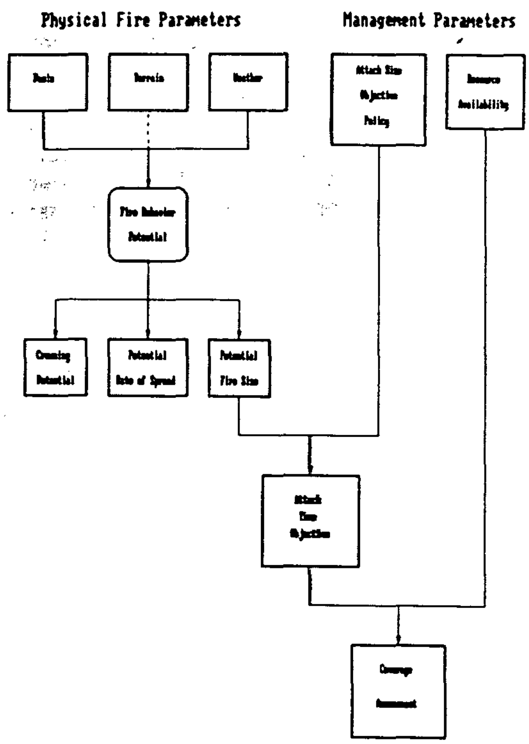

FIG. 2. Spatial modelling of the fire environment used to derive the coverage assessment.

The third interpolation technique uses a weighted moving average. This technique interpolates values between stations by considering FWI output values from all close weather stations and weighting them with a function of the distance from the station to the point of interest. The definition of a close weather station is purely subjective with the intent of reducing calculations by rejecting distant weather stations

Weighting functions vary, and for this study, station values were weighted by the inverse of the distance away from the point of interest squared. In mathematical form, the weighting scheme would be

$$x' = \frac{\sum_{i=1}^{n} x_i/d_i^2}{\sum_{i=1}^{n} 1/d_i^2}$$

here x represents the station values, d represents the distance of the station from the interpolation point, and n represents the number of weather stations used in the calculation. The interpolated value is x'.

The weighted moving averages technique's advantage is that it produces an isopleth map with smooth gradients for the FWI output values between stations. One disadvantage of this technique is that it disregards the climatological and topographical arguments used in designating assignment regions, such as winds channelled by a valley. However, gradients in environmental values caused by gradual changes in elevation are represented by this technique. Figure 1c shows a weighted moving averages analysis of the BUI for May 4, 1988. BUI values at the weather stations are shown but the values throughout the map vary gradually. The boundaries between two classification represent contours of constant value.

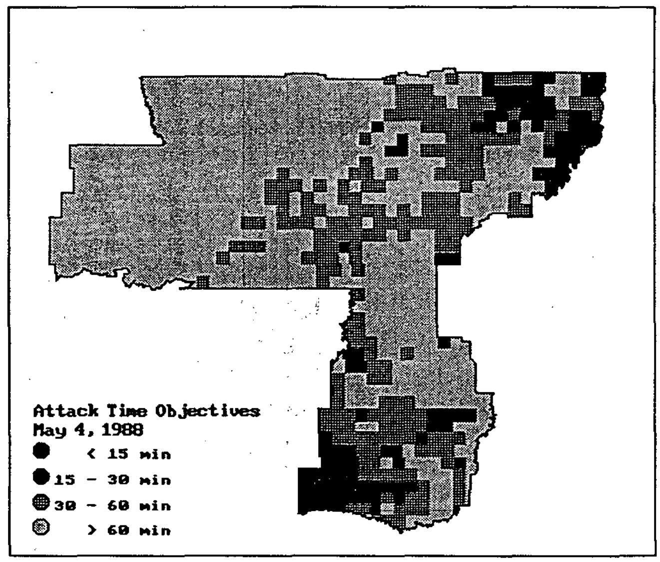

FIG. 3. Attack time objectives analysis for May 4, 1988, showing the elapsed time required for a potential fire in each cell to reach the attack size objective of 1.2 ha. Cell sizes are 2331 ha.

Spatial Modeling of the Fire Environment

Forest inventory data and interpolated weather can be integrated to predict potential fire behavior spatially. This information can be used to conduct an assessment of coverage efficiency for deployment planning. The following describes the methodology of such a technique, as used by IFMIS. The data used for this paper are from the Whitecourt Forest in the Province of Alberta, as shown schematically in Figure 2.

FOREST FUELS

Most forestry agencies have compiled forest inventories over large areas giving a detailed description of forest stands within each area. Stand descriptions include information on tree species, densities, heights and stand age. Alberta's Phase 3 Forest Inventory, completed in 1984, has evaluated the province's forest resources and stored the information in a database at a 64.75 ha cell size (0.6475 square km).

FBP fuel types can be interpreted from forest inventories to give a spatial representation of FBP fuel types. The decision criteria used to interpret FBP fuel types from the Alberta phase 3 forest inventory is outlined in Table 1.

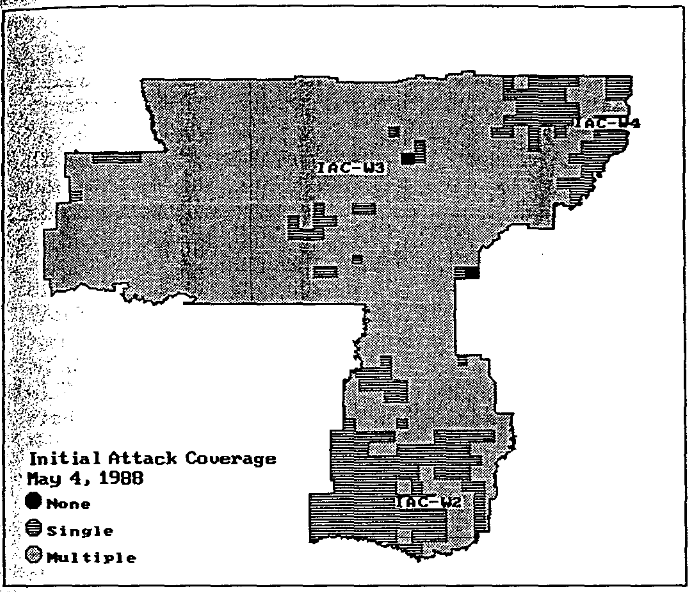

FIG. 4. Initial attack coverage assessment for May 4, 1988, using three initial attack crews: IAC-W2, IAC-W3, and IAC-W4.

TERRAIN

The FBP system allows for terrain inputs when calculating predicted fire behavior. Adjustments are made for slope and aspect when predicting to the forward rate-of-spread. Terrain was not used in this study; however, its use in the future would likely produce better estimates of fire behavior potential.

FORECASTED FIRE WEATHER

Using forecasted FWI system inputs (temperature, relative humidity, wind speed, and precipitation), the forecasted FWI system outputs are computed for each weather station in the protection area. A forecasted field is produced for the area by interpolating the values at intermediate points from the values at weather stations.

WILDLAND FIRE BEHAVIOR POTENTIAL

A spatial representation of potential fire behavior can be built by using the FBP fuel type(s) and the interpolated weather at each cell as FBP system inputs. FBP system outputs include forward rate-of-spread, crowning potential, fire shape, size, and perimeter.

ATTACK TIME OBJECTIVE

The goal of preparedness planning systems is to reach and conduct initial attack on all fires before they reach a threshold size. The threshold size is called the attack size objective. Using the FBP system outputs, the time it takes a fire to reach the attack size objective can be calculated. The time elapsed is called the attack time objective. Attack time includes report time, get-away time, and travel time of the initial attack resources.

Cell by cell fire behavior potential calculations produce a map of required attack times to meet the attack size objective. This map is referred to as the attack time objectives map. Figure 3 shows the May 4, 1988 attack time objectives analysis for the Whitecourt Forest in Alberta using the attack size objective of 1.2 ha. With this map, a forest protection officer can see areas of concern (low attack times) when rapid initial attack is required to prevent the escaped fire scenario. Note that in figures 4 and 5, a larger cell size (2331 ha or 23.31 square km) has been used to enhance clarity.

COVERAGE ASSESSMENT

The fire manager can quantitatively evaluate the deployment of fire control resources based upon the number of resources that are able to meet the attack time objective for each cell in the forest. Figure 4 shows the initial attack coverage assessment of 3 crews for May 4, 1988. The coverage value (none, single, multiple) indicates the number of resources (0).

Discussion

The deployment analysis technique as described in this paper can aid fire managers by assessing initial attack coverage effectiveness. Using this technique, the manager can deploy resources and assess the coverage. Any weaknesses in the deployment are recognized, resources are repositioned, and another coverage assessment can be produced. Using current microcomputer technology, IFMIS allows the user to consider various deployment strategies within minutes.

The proposed system does have limitations. Its accuracy depends greatly on the accuracy of the data, the interpolation technique, and the models. This is easy to overlook when faced with the final product. As IFMIS is installed in various locations in western Canada, an assessment of these problems and any others will determine the practicality of IFMIS as a fire management support tool.

Conclusions

Current presuppression preparedness systems integrate fire weather values spatially into their decision making, although at a cartographically generalized scale. With the development of computer based systems such as IFMIS, interpolated weather and forest inventory data can be used to derive cartographically detailed interpretations of predicted fire behavior. The result will be more effective positioning of initial attack resources. In addition, there is a potential for large savings of presuppression dollars by ensuring that resources are pre-positioned optimally, and only when they are needed.

Table 1. Alberta Phase 3 Inventory to Canadian Forest Fire Behavior Prediction (FBP) System fuel type interpretation.

Species	Density (% crown closure)		Age (years)	FBP fuel type
Treed marsh Open muskeg				C1 Spruce - lichen woodland
Black spruce White spruce Balsam fir Tamarack larch	≤ 30%			C1 Spruce - lichen woodland
Black spruce White spruce Balsam fir Tamarack larch	> 30%			C2 Boreal spruce
Coniferous scrub				C2 Boreal spruce
Pine	≤ 70%	or	≥ 30	C3 Mature jack pine or lodgepole pine
Pine	> 70%	and	< 30	C4 Immature jack pine or lodgepole pine
Douglas fir				C7 Ponderosa pine or douglas fir
Aspen White birch Balsam poplar Deciduous scrub				D1 Leafless aspen (dependent on season)
Brush Clearing Cultivated Grass				O1 Grass
Clearcut Scarified			≥ 3	O1 Grass
Clearcut Scarified			< 3	S1 Jack pine lodgepole pine slash
Insect killed Various killed Windfall				S1 Jack pine lodgepole pine slash
Recent burn Barren soil Glacier Barren rock Sand Water				NF Non-fuel

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