FOREST FIRE DANGER ASSESSMENT :
COMBINATION OF METHODS FOR EFFICIENT DECISION MAKING

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Abstract

Forest fires danger is one of the main emergencies in many countries all over the world. To reduce the consequences of their occurrences, forest managers or fire officers use prevention, by reducing biomass, by locating fighting teams in exposed areas or by patrolling. To fight efficiently, they use suitable means: trucks, planes, helicopters, fire retardants. The keypoint of prevention and fighting is the assessment of danger, which can be done from different points of view and at different time scales: from historical data, real time monitoring or forecasting.

This paper describes a combination of assessment methods, integrated in a decision aid system. Four methods are used, related to: inflammability of dead fuels and live fuels, which assess the behaviour after ignition, fireline intensity, which assess the difficulty of fighting and fire occurrence, which assess the frequency of fires from historical data. The integration of these methods is done using a knowledge-based approach, in association with a relational database and a GIS (Geographic Information System).

Finally, we present some results obtained on the test region of Mount Parnis, near Athens in Greece.

Keywords

Forest fires, Danger assessment, Decision support,
Expert system, GIS (Geographic Information System).

1. Fire Danger Rating methods : literature review

The most commonly used definition of Fire Danger is the resultant often expressed as an index of both constant (fuel types, topography ...) and variable (weather conditions) danger factors which affect the ignition, spread and difficulty of control of fires and the damage they cause (Chandler et al 83).

Several countries have at different times set up various methods for forecasting the fire danger rating (Chandler et al 83), starting from a number of different assumptions, even though these have in general been based essentially on the consideration of meteorological factors. A synthesis of the main methods adopted and their particular structure is briefly presented.

All these systems developed in various countries, although varying in appearance and complexity, have the common objective of obtaining a relatively simple and comparable measure of the inflammability of forest fuels from day to day.

The US method (The NFDRS, The National Fire Danger Rating System), is based on the mathematics and physics of fuel moisture and heat exchange as they affect fuel moisture variations (Deeming et al 72) and on laboratory experiments about the influence of various fuel and weather factors on fire behaviour (Rothermel 72). The NFDRS interprets the moisture level of a wide range of forest fuel sizes through the use of three representative classes of fuels with different drying states. It includes a fire rate of spread component and a component to represent the effect of long-term drying on the fuel. It also produces an index representing the fire intensity (BI, Burning Index) and it has a number of other indexes that can be used to indicate the level of other fire factors such as ignition possibility or rate of spread.

The Canadian method was largely developed from statistical analysis of large quantities of field data. The tables were empirically constructed by putting together weather, fuel moisture and fire behaviour data (provided by small test fires). Van Wagner describes this method (Van Wagner 74) which has been implemented on a computer (Kourtz 80). The index is based on daily measurements of weather factors (wind speed, rainfall, temperature and relative humidity of the air) recorded at 12 a.m..

These authors consider that it is impossible to give a complete indication of fire danger rating for a given day only with one value. Based on the water content of three types of fuels, combined with the effect of the wind on the fire behaviour, this Fire Weather Index (FWI) is divided into six components:

. three primary sub-indexes representing the water content of a layer of forest bed and other light fuels (FFMC, Fine Fuel

Moisture Code), the water content of a layer of compact organic matter (DMC, Duff Moisture Code) and the water content of a deep layer of compact organic matter (DC, Drought Code);

. two intermediary sub-indexes representing the rate of spread (ISI, Initial Spread Index) and the total quantity of fuel available for combustion (BUI, BuildUp Index);

. a final index representing the amount of energy produced per time unit and length unit of the flame front (FWI, Fire Weather Index).

The originality of the American and Canadian works is that they take into account different parameters from different components: fuels factors, human factors and meteorological factors. These global approaches (including the most important danger parameters) result in a risk integration. On the contrary, the other methods presented below do not have this characteristic.

The Australian method was developed, as the Canadian one, from statistical analysis of large quantities of field data (McArthur 66 a et b). McArthur designed a meter based on fire behaviour data measured after some 800 test fires with typical fuels. The tabulated indices have been reduced to equations (Noble et al 80) and programmed for use on a pocket calculator (Crane 82). This method is based on the consideration of the following parameters:

- fuel water content and its daily variation
- both open field and inside the wood wind speed
- fire rate of spread
- fuel load and its relation with the rate of spread
- slope
- height of flame as a function of :
    fuel moisture content, fuel load and wind speed.

Two indices are calculated. The first one is a cumulative index (based on evapotranspiration, rainfall and air temperature) providing the degree of inflammability of the fuel . The second one is an index that determines the level of fire danger, the speed of propagation and the difficulty of extinguishing the fire, and has a closed scale ranging between 0 and 100.

In France, a method based on the major weather factors and on empirical equations derived from experimental studies is used (Sol 92). The estimation of the risk level is based on meteorological forecasting and the actual system, developed by the National Weather Service, includes weather parameters and soil water content. The risk level is described by five levels (low, moderate, medium, high, very high).

Two other methods are integrated in the Expergraph system (Wybo 92), one is proposed by Carrega (Carrega 90). The Carrega "85/90" index for fire generation and spreading, initially elaborated for the French Riviera, turned out to be applicable to the entire south of France where it was tested by the National Weather Service.

The formula is : $I = (500 - (H.\sqrt{R} / V).C) / 25$

where R is soil water reserve according to Thornwaite (saturated at 150 mm), H is the minimum air relative humidity in percentage, V is the wind speed in Beaufort degrees and C is a phenological coefficient of vegetation that ranges from 0.8 to 1. The "I85/90" index is defined as ranging from 0 to 20 (maximum risk). Thus, the fire hazard is low up to 8, moderate up to 14, severe up to 18 and very severe beyond this value.

The second method links, for each location, an estimation of the rate of spread with the time needed to reach it. These values are used to estimate the amount of burnt surface. This index gives an idea of the size of the fire that the firefighters will be facing.

In (ex) USSR, the most widely used method (Nesterov 49) is an index of fuel inflammability, which is a cumulative index calculated during the interval of days in which there has been no daily rainfall exceeding 2.5 mm.

Other approaches have started from the consideration of forecasting methods adopted in Canada and the USA, integrating and modifying them according to the different conditions of climate and vegetation prevailing in the respective countries. Other authors (Chuvieco 89) use a G.I.S. approach to take into account a danger index based on several parameters such as: slope, exposure, altitude and distance to road.

2. Knowledge based system coupled with a G.I.S. for wildfire danger assessment

The main aim of this study is to provide users with an efficient set of data to support their decisions for prevention and fighting of forest fires. We have decided, as it has been done in the methods reviewed above, to build several indexes rather than an integrated one, each of these indexes being representative of an aspect of danger.

2.1. EPOCH # 40 methods

The study of forest fire behaviour shows four steps:

- is there any reason for a source of energy to be present ? In other words, in each location, what is the probability for a fire start ?
- the starting point of fires is generally on the ground, as such, is the dead fuel on the ground dry enough to allow an extension of the initial energy ?
- once the dead fuel on the ground is burning, the fire will really expand if the live fuel is dry enough to burn and as such, increase the biomass involved and consequently the energy of the firefront.

- to estimate the difficulty of fighting, the most suitable index is the fireline intensity.

In the frame of project EPOCH # 40 (supported by the EEC) four fire indexes have been established in order to represent these four steps:

- the Fire occurrency
- the Average Inflammability of Dead Fuels
- the Average Inflammability of Live Fuels
- the Fire Severity

2.1.1. Fire occurrency

To estimate the spatial density of fires in an area, we use a list of fire events, giving their date and location. First, we fix the period of time for which the fire events are processed, for instance the last five years. Then, we calculate all the distances between fires, we sort the results in classes and we determine the more frequent class, which distance is used for integration.

The next step is to create a map (figure 1), giving for each pixel the density of fire events. For each event of the list, we create a circle centred on its location and which radius is the distance used for integration. Then, for all the pixels included in this circle, we add a constant to the current value.

2.1.2. Average Inflammability of Dead Fuels

The Average Inflammability of Dead Fuels is derived from the estimation of the thin fuels (1hr-timelag) moisture content, as they change under different meteorological conditions and during day and night hours. This index has also been considered as independent from the type of fuel model. Thus, this index has been estimated by the two following steps:

Step 1: estimate the fine fuel moisture content from tables as they have been proposed by Botehlo [1]. The relative humidity and the temperature during the day and night are the meteorological parameters which have been considered in these tables, on which are applied correction factors, according to the different hours of the day and night as well as for the amount of rainfall per week.

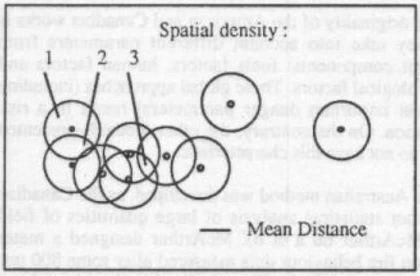

Figure 1 Fire occurrency computation

in these tables, on which are applied correction factors, according to the different hours of the day and night as well as for the amount of rainfall per week.

Step 2: classify the values of the fine fuel moisture content in terms of four average inflammability levels (Low, Medium, High, Very High).

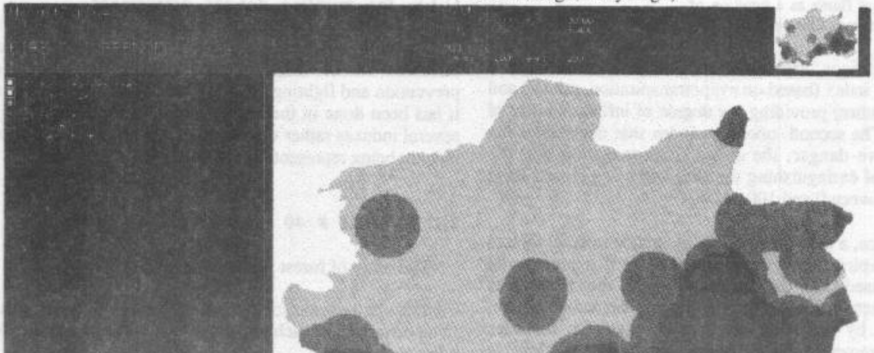

Figure 2 : Fire occurrency map (Mt. Parnis)

2.1.3. Average Inflammability of Live Fuels

The average inflammability of live fuels is derived from the estimation of the inflammability of live fuels of all the fuel models. The fuel models which are considered here are those represented in the Mt Parnis area, but this method can be extended to other models. The estimation of this danger index was done in four steps:

Step 1: Two inflammability indexes were given to each one of the understory species of the fuel types of Mont Parnis. These indexes express the inflammability level of species during summer, and more specifically the first one gives the inflammability level for the months May, June and July (early summer) and the second, for August, September and October .

The selection of these indexes was done by Valette (Valette et al 90) according to flammability studies done on species of southern France which are similar to those of Mount Parnis.

Step 2: The average inflammability index of each fuel model was estimated by the following way:

- evaluate the volume (coverage x cover) of each species,
- multiply the volume by the inflammability indexes (early / late summer),
- make the sum of all the species and thus one index corresponds to each fuel model.

Step 3: The number of classes and the class limits were determined according to the values of the fuel models indexes and also to the needs (of detailed estimation). Thus, four inflammability classes were created.

Step 4: Finally, each fuel was classified in terms of the average inflammability of its live fuels during summer period (early and late).

2.1.4. Fire Severity

The fireline intensity is the parameter considered for the Fire Severity estimation. The interpretation of this parameter is best related to the prediction of severe fire behaviour (Rothermel 83).

The steps to estimate this danger parameter were the following:

Step 1: Both fuels characteristics and meteorological parameters were considered. From the fuel models of Mt Parnis and the relative humidity and temperature, the fireline intensity was calculated as one of the outputs when applying Rothermel's model and especially BEHAVE equations, in order to predict the rate of spread without slope and wind effects.

Step 2: Four classes of fire severity have been created from the values of fireline intensity derived from the above calculations, based on the classification given by bibliography (Rothermel 83).

2.2. A knowledge based approach linked with a G.I.S. for fire assesment

Geographic Information Systems (G.I.S.) have a significant impact on the quality and the effectiveness of forest management. To plan and manage forest effectively, both accurate and appropriate data for modeling information is needed. In addition, this information must be easily maintained and updated to incorporate current information from a variety of sources. Current applications incorporating G.I.S. technology have clearly illustrated its importance and viability as a mechanism for improving program management and short-term decision making.

In order to increase the performances of a GIS we have linked this tool with an expert system. Thus, the Expertplan system (Wybo 91) is used to estimate the danger indexes. The knowledge formalism consist in production rules, wherein expert knowledge is expressed as a series of independent statements with each statement being encoded as an independent condition-conclusion pair. This formalism has proven to be the most commonly used declarative representation in operational expert systems.

After collecting knowledge and writing the corresponding set of rules (in a text file, using a small set of symbols), it is necessary to build a knowledge base which can be used for deductions. To do this, we have designed a rule compiler, which role is to verify the syntax of the rules and to build the knowledge base, containing parameters, rules and relations between them: which parameters are conditions in a rule, which rule conclude on a parameter.

Once a knowledge base has been designed and tested with EXPERTPLAN, it is necessary to describe (in database tables) the characteristics of the parameters: constant value or map, value, name of the map. It is also necessary to associate to each parameter which format is a map a set of classes. These classes represent all the possible values for a parameter. They are associated to colours for the display.

When all these specifications are ready, EXPERTCARTE (Wybo 91) a second expert system designed to manage raster maps (from the G.I.S.) assesses the Danger rating indexes presented above on maps. To achieve this task, the maps of input parameters (used in the deductions) have to be created in the G.I.S.

During a deduction session, EXPERTCARTE updates (pixel by pixel) the maps of the deduced parameters. After the deductions, all the output parameters which format is a map are updated, and their versions (date and time of update) are also updated in the database.

The main characteristics of this expert system are:

- data is represented as raster maps (one per parameter of the knowledge base),
- there is no direct interface with the user.
- it has the ability to interact with the Database Management System.

In fact, it receives the knowledge base name with which it shall work and as from then, it loads the parameters (present in the knowledge base) characteristics from the database. These characteristics include the format of data (raster map, class, constant value), the version (update time) and the set of classes describing all the possible values of each parameter (which will appear as different colours of the map on display).

Starting from the map of fuel models, relative humidity and air temperature several output maps predicting fire behaviour are derived. The fireline intensity map is selected and its pixels are interpreted in terms of fire severity.

Figure 3 shows how the fire severity is computed, by a combination of equations and expert rules contained in the knowledge base.

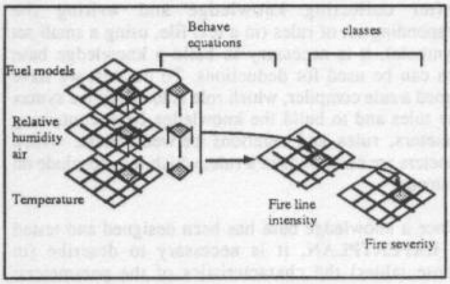

Figure 3: Danger Index Maping : the Fire Severity

Conclusion

The integration of danger rating methods in a decision support system gives to managers a powerful tool for decision making. Two important features must be achieved: update these data by monitoring the situation and allow experts to create and update their own methods.

The FMIS system (Wybo et Meunier 93) has been designed to reach these goals by associating autonomous processing and knowledge based assessment of data.

Automatic acquisition of data is essential to danger assessment in the sense that managers must be aware of the situation and its evolution but, to be fully efficient, this automation has been extended to the management of data processing and danger indexes updating.

The four indexes presented in this paper give to the managers a precise idea of the danger level in the different aspects of wildfires. This information can be used for prevention tasks, for instance to start patrolling in most sensitive areas; it can also be used to help decision making when a fire event occur.

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