

Fire Detection as a Support to Dispatching

A pilot project in Portugal

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1 Introduction

Forest fires are a complex activity that requires the cooperation and support from various institutions and systems to manage them. The scientific community is also a part of this group and wishes to give its contribution.

Adequate decisions on dispatching are essential to assure a cost effective, quick and safe suppression of forest fires. Knowledge on fire behaviour is essential to base fire suppression activities, namely dispatching decisions.

Advanced Fire detection systems can be used to support these decisions as well.

During the recent years with the support of the EU a strong effort was developed to involve results and products of research projects into operational practice.

The experience of a pilot project coordinated by the author in Central Portugal is presented.

2 Fire behaviour models and algorithms

2.1 Main factors

Forest fires depend on many factors, some of them of social or economical nature, others of physical nature. Physical factors can be grouped in three main sets:

- Topography
- Vegetation cover
- Meteorology

Although these sets of factors are not independent from each other it is convenient to deal with them separately.

Topography is practically a permanent factor and human action cannot modify it. Vegetation cover may change through the years and it is the only factor that can be modified and controlled by human activity. Meteorology changes very rapidly and although it cannot be controlled by us we can understand its role and predict its evolution.

2.2 Meteorology

Meteorological factors affect forest fires in the long and in the short term. We consider the long-term action that of parameters – such as precipitation, solar

radiation, air temperature and relative humidity – that modify the development and dryness condition of forest fuels that determine the relative facility of fires to start and to spread. The short-term factors – like wind velocity and direction and atmospheric stability – that affect directly the propagation condition of the fire.

It is well known that there are days in which meteorological conditions are more favourable than in others to have fire starts and fast fire propagation. Daily values of the parameters of the first group can be associated to determine the fire danger associated to meteorological conditions for a given region.

Fire danger rating:

- Low danger
- High danger
- Very high danger
- Extreme danger.

The attitude for dispatching must certainly change with the level of daily fire danger.

The Canadian Fire Danger Rating System is very simple and can be used to estimate very accurately the daily probability of having fires or dangerous fires.

It requires daily values of: Air temperature, relative humidity, wind velocity and precipitation.

Moisture content indexes

Fine Fuel Moisture Code (FFMC) – Numerical code related to the moisture content of dead fine fuels.

Duff Moisture Code (DMC) - Numerical code related to the moisture content of the duff layer.

Drought Code (DC) – Numerical code related to the soil water content.

Each one of these codes is evaluated from meteorological data using a set of formulae that produces a numerical value that increases with the deficit in water content. The relationship between this value and the actual moisture content of the fuel must be determined by calibration case by case. In Viegas et al. (2001) it was shown that the *DC* is a good estimator of the moisture content of shrub vegetation during the fire season.

Fire behaviour indexes

Initial Spread Index (ISI) – Numerical index incorporating fine fuel moisture content and wind velocity to estimate the rate of spread of a fire front on flat terrain in the absence of suppression, as happens during the initial stages of a fire. Its application to particular fuels requires calibration.

Build Up Index (BUI) – Integrates the two remaining codes, *DMC* and *DC* to estimate the proportion of available vegetation – medium and fine particles – that will effectively participate in fire spread. As it is well known this fraction is dependent on the moisture content of the various components of the fuel bed.

Fire Weather Index (FWI) – Fire danger index related to meteorological conditions.

The final result of the system is a result of the previous ones. The FWI is directly related with the possibility of having fires and with their relatively fast propagation. Joining the initial spread index ISI with the available fuel index BUI the FWI becomes truly a fire line intensity indicator. It could be considered a fire behaviour index. It is at the same time a good indication of the probability of ignition – related to the fine fuel moisture content – and of the probable extension of the fires – related to the rate of spread through ISI – and also to the difficulty of extinction – related directly to fire line intensity or to its equivalent flame length.

2.3 Vegetation

The vegetation that exists in rural areas can be considered as a potential fuel that can support the start and propagation of a fire. At this stage we make no distinction between an agricultural and a forested area in its general characterisation. The particular case of houses or structures that may exist in the vicinity of rural areas shall be dealt with separately.

In physical terms natural vegetation that supports forest fire propagation is a solid porous fuel. It is composed by particles of wood –essentially cellulose – with different physical and thermal properties that may affect fire propagation.

In a macroscopic description of the vegetation that is present in a given area of the forest we can consider the following items: (i) Fuel layers; (ii) Horizontal and vertical continuity; (iii) Homogeneity and specific composition, and (iv) Fuel bed properties.

Fuel layers

In the general case we may have the following types of fuel layers:

Aerial fuels – composed by the foliage and branches of trees forming their canopies; these are usually separated from the ground by a trunk.

Surface fuels – composed by vegetation near the ground, like herbaceous or shrubs, or above the ground, like dead foliage and litter.

Ground fuels – organic matter that is below the horizon level and can support glowing combustion fire.

We shall designate each one of these layers as a fuel bed. Most of our considerations deal with surface fuels but we cannot forget that the other two layers may exist as well, below and above the surface layer.

Horizontal and vertical continuity

When several fuel layers exist their composition may or may not be continuous in the vertical direction. Vertical continuity is very important to assess, especially between the surface and the canopy layers because of the possibility of having crown fires. This continuity does not mean necessarily a physical contact between the particles of both layers. As it is well known if the distance between the base of the canopy is lower than the flame height of the surface fire below it crown fire is very likely to occur.

Horizontal continuity is required in each fuel layer for fire to spread under normal conditions. Again this continuity does not require a physical contact between adjacent particles. Provided that the heat flux from intensity one burning particle is enough to reach its neighbour in conditions to inflame it we can consider that

continuity exists. Fire-breaks or fuel-breaks are very important examples of horizontal discontinuities in the fuel bed layer that require our attention.

Homogeneity and specific composition

Each fuel layer may be composed of the same type of fuel particles, with the same or with very similar properties, like the fuel bed composed by dead needles on the ground of a pine stand. In the general case we have heterogeneous fuel beds with particles from different properties and from different species.

The plant species that are present in a given fuel bed characterise it quite well, as different species may have their own flammability and combustibility properties. It is therefore necessary to characterise the fuel bed by its composition in terms of species that are present.

Fuel bed properties

Each fuel bed or fuel layer can be characterised by the following parameters:

Fuel bed height – defined by the thickness of the layer; in the case of the surface layer it is the average height of the vegetation measured above the ground.

Fuel load – defined by the amount of fuel mass (considered on a dry basis, i.e. without any water content) of vegetation per unit of area.

Fuel bed porosity – defined by the volume of air inside the fuel bed divided by its total volume.

Bulk density – defined by the mass of fuel divided by the total volume it occupies.

Packing ratio – defined by the bulk density divided by the particle density.

These parameters are not independent from each other. They are given here because they are found commonly in the literature.

If we look more in detail into each fuel layer we shall recognise that it is composed by fuel particles of different physical and chemical properties.

Vegetative state

Dead particles – are those that do not receive any vegetative input from the plant that originated it; strictly this concept applies to parts of the plant that are separated from it – like a dead branch or leaf that has fallen on the ground, but it may also apply to dead parts of a living plant.

Live particles – are those that participate on the vegetative life of a plant.

Dead particles depend much more on the atmospheric conditions to gain or lose moisture and to ignite during a fire. Live particles have in general higher moisture content and may not participate in the propagation of a fire in certain conditions.

Particle size and shape

Fuel particles are solids of different shapes. In some cases we can find simple solids to which they are alike; some of them are similar to circular cylinders, others to rectangular cylinders or to spheres. The shape and size of the particle is very important for the process of heating and ignition during fire spread.

We can define a very important property of the fuel particle that is its surface to volume ratio σ defined by:

$$\sigma = \frac{S}{V} \quad [\text{cm}^{-1}]$$

This parameter is expressed in units of length raised to the power (-1). We can use either *m* or *cm* to express it.

We can use the minimum dimension of the particle, like the particle thickness or diameter to define the following particle size classes:

Fine particles – if the minimum dimension *d* of the particles is below 0.5 cm.

Medium particles – if: $2 \text{ cm} < d < 0.5 \text{ cm}$.

Large particles – if: $d > 2 \text{ cm}$.

Physical properties

Volumic mass – is defined by the density or the mass per unit volume of the particle ρ_p . In general this is roughly the density of wood that is of the order of 600 to 800 g/dm³.

Specific heat – that is the amount of heat that is required to raise the temperature of the unit of mass of the particle by one degree; C_p is expressed by Joule/g °C. The value of C_p depends on the fuel species and on its moisture content.

Heat content – is defined by the amount of energy that is released as heat by the complete combustion of a unit mass of fuel; H_f is expressed in Joule/g. Its value depends on the species and on its chemical composition but for the majority of species the value of H_f is in a relatively narrow range, so that it is common to consider its average value as characteristic of the heat content for the majority of forest fuels.

Chemical composition – chemical composition of natural vegetation is cellulose and hemi-cellulose.

Temperature of ignition – it is defined by the temperature reached by the fuel particle when it ignites. This temperature is in the range of 320 to 340°C.

Moisture content – the amount of water in the fuel particle is a complex parameter because it is partially an intrinsic property of the fuel but also a parameter that derives from the ambient conditions. Water exists in the fuel both as free water and as water that is part of the plant cells and tissues. Free water is more easily exchanged between the plant and the atmosphere, while the bound water requires more energy to be released from the tissues.

There is a direct correlation between FMC of dead fine fuels and the possibility of fires to ignite and spread more or less easily. It is found that for $m_f > 30\%$ the number of fires and the burned area in a given region is very low, while the contrary occurs when $m_f < 10\%$.

2.4 Wind and slope effects

Wind and slope interact with the fire and modify its behaviour in a very complex way. In the general case they act together but it is convenient to understand their roles separately at first before looking at their joint action.

The rate of spread increases steadily for upslope propagating fires. The rate of spread can be ten to twenty times the basic rate of spread when the slope increases from 0 to 30 or 40°. On the contrary the rate of spread of down-slope fires is practically constant and independent of the slope angle. Its value is very similar to the basic rate of spread R_0 .

Wind has a similar effect on the fire front as slope. It induces an inclination of the flame front and a more intense heating of the unburned particles. So the rate of spread is much higher for wind driven fires. The rate of spread can be even 100 times higher than for the case of no wind. The effects of wind is very dependent on the fuel bed porosity: porous fuels – like herbaceous vegetation - will be more sensitive to wind effect while more compact fuel beds – like litter or slash - will increase much less their rate of spread with wind. Contrary wind does not affect the rate of spread that is of the order of R_0 .

When wind and slope gradient are not parallel we can consider that their effects add as a vector sums of the corresponding rate of spread vectors. In the case of a closed fire line in complex topography the fire perimeter will have sections with different dominant effects: some with positive effect of wind and negative effect of slope, other where both are positive and so on. The fire front will have complex orientations according to the local effects of wind and slope.

2.5 Concept of Fire Line Rotation



Figure 1. Laboratory experiment of a non-horizontal fire front spreading on a 40° slope.

In the general case the movement of the fire front is composed by a translation and a rotation. Rotation exists when there are transverse fluxes along the fire front. Examples of this situation are fire fronts spreading upslope or with favourable wind when the local rate of spread is not parallel respectively to the slope gradient or to wind velocity. In these cases the fireline tends to rotate until it becomes parallel to wind or slope gradient direction (cf. Figure 1).

The only stable fire spread situations are the flanks (parallel to wind) and the head fires (perpendicular to wind).

2.6 Fire Behaviour Prediction

Knowing the laws that govern the spread of elements of the fire line at given fuel and ambient conditions using appropriate algorithms to predict the movement of the fire line elements it is possible to predict fire behaviour.

The majority of fire behaviour algorithms are based on the concept of quasi-independent movement of fire line elements in the sense that their spread properties depend only on the local conditions. This is not the case when there is a string interaction between elements of the fire line, as in the cases presented above when rotation exists.

Almost all fire behaviour models rely on Rothermel's model to estimate the local rate of spread including wind and slope effects.

A fire behaviour prediction system designated *FireStation* was developed by Lopes et al. (1998) it incorporates wind field prediction models and suppression actions can be simulated. *FireStation* runs in a PC on a CAD system to display geographical data. It requires a DTM of the terrain a fuel model cover and meteorological data from stations located inside the domain of calculation must be specified. The Canadian Fire Danger System is incorporated to estimate the moisture content values of fuel elements and also the fire danger index. Diurnal variation of the moisture content can be simulated by the system. Wind velocity and direction must be specified at each meteorological station for given time periods and the wind field over the terrain is calculated using Nuatmos model.

Fire ignition can be introduced as a point a line or an area of ignition. Fire spread simulation can be run with or without considering the wind field. Several interesting outputs like the fire line intensity contours or the fire perimeter growth can be plotted easily. Fire suppression tactics can be simulated and their effectiveness can be assessed very quickly running the system.

At present we consider that *FireStation* is in a development stage and we are using it to analyse past fires and to assess its accuracy in comparison with actual data from experimental or from real fires. Nevertheless it has been used tentatively in operational conditions in the context of a pilot project that is described below.

3 Support to dispatching

3.1 Introduction

The decision to dispatch fire-fighting means, especially aerial means, must be supported on objective ground. The possibility of visualizing directly what is happening in the fire using fire detection systems can be very useful for this purpose as it can be done immediately without the need of making any radio connection to listen to a voice communication. Besides this more than one fire can be observed simultaneously if they fall in the observation field of the existing observation cameras. Moreover if infra-red cameras are available it is possible to observe the development of the flame front even through the smoke and the fog that may impair visual observation of the fire by the personnel from watch towers.

3.2 *Fire Detection Systems Project Eagle*

A Pilot Project designated Project Eagle was developed in Central Portugal with the purpose of testing the application of advanced technologies and decision support systems in the management of forest fires. This project was supported by the Forestry Service and performed by ADAI in combination with other institutions. Its area of application was the district of Coimbra and it was based at the Coordination Centre of Poiares. Five different electronic systems were installed at two watch towers and at an airfield located in a radius of 15km from the Centre. Two of the systems had visual and infra-red cameras. These two systems were produced by IZAR and



Figure 2. Controlling fire detection and fire behaviour prediction systems at the Coordination Centre of Poiares (Portugal).

by Teletron and both had the capacity to detect fire starts automatically. The remaining three had only video cameras. Two systems used GSM telephone communication to transmit images and data. The systems were operated throughout the summer season and were manned by personnel from ADAI team, with the support of the manufacturers of the equipments.

The reliability of the systems was quite good and their general performance was considered very satisfactory. The capacity of detecting fires automatically was demonstrated in several occasions. It was nevertheless the capacity to monitor fire spread that was most appreciated by the operational services, as was described above.

4 **Fire safety**

4.1 *Introduction*

Personnel safety must be a concern at all stages of fire management. Dispatching has a great responsibility in allocating personnel to right places at the right time, in order to avoid entrapments. Great attention must be paid to the accesses and to the evolution of meteorological conditions, especially of wind, during the following hours. The attitude of not sending fire fighters to places where their life can

be put in danger must be enforced as a human life is always worth much more than a group of trees.

Two study cases are presented to illustrate the importance of assessing terrain and meteorological conditions to avoid fire entrapments.

4.2 Case 1 – Tabuaço

This accident occurred near the town of Tabuaço, in the North of Portugal on the 10 July 1999. Seven Firefighters were involved in the incident and two fatalities were registered. This crew of a fire truck was attacking a fire descending a slope towards the bottom of a small valley where they were. A wind direction shift and an increase of its velocity caused the fire to become very dangerous and surprised the fire fighters. The fire cut the road below and above their location and the group split into three small groups each one with a different escape strategy.



Figure 3. General view of the site of the accident of Alvão in which one fire fighter was killed.

Two fire fighters choose to run upslope along a stretch of unburned vegetation in order to reach a secondary road and a safety zone previously defined. They managed to reach this road but in the meantime the advancing fire overwhelmed them. All the other elements escaped unharmed.

It was later found that this wind field change had been predicted by the Meteorological Service many hours in advance but this prediction was not considered by the commanding structures. This accident contributed for a change in this attitude.

4.3 Case 2 – Alvão

The second case occurred also in Northern Portugal near the Serra of Alvão on the 24 June 2000. The site of the accident was a very steep slope (Canyon) and around 20 persons were in the area of the incident when it occurred. A young fire fighter was killed by the fire in this accident.

The group was attacking a slowly burning flank fire along a very steep slope between two roads. There was no anchor at the bottom of the slope and the fire reached the base of the canyon (water line) in which the group was working. A fire chief that was posted as a watchout gave the alarms and all the personnel ran into the already burned area. One fire fighter got confused and instead of running along the slope towards the already burned area choose to escape upslope to the road. The advancing fire caught him before reaching the road. In spite of the very intense fire spread fortunately the crowns of the pine trees did not catch fire otherwise this disaster could have had a much greater dimension.

5 Conclusion

Dispatch activities can be supported by new advances in information and communication technologies. Scientific research on forest fire behaviour can contribute to make the entire process more objective and less dependent on the expertise of individual persons in charge of managing the fire incidents. Fire behaviour simulators can provide some guidance although at their present stage of development they are still not fully reliable.

Safety of the personnel involved must be an ever-present concern, starting on dispatch and ending on the attitude of fire fighters and all personnel involved in fire suppression activities. Great attention should be paid to terrain conditions and to possible changes in meteorology.