Enhanced forest fire risk assessment through the use of fire simulation models

Joaquin Ramirez
Tecnosylva
jramirez@tecnosylva.com

Miguel Mendes
Tecnosylva
mmendes@tecnosylva.com

Santiago Monedero
Tecnosylva
smonedero@tecnosylva.com

ABSTRACT

Forest fire risk assessment is an important task for forest fire management and planning. This paper presents current work on the definition and implementation of forest fire risk assessment models in the Wildfire Analyst™ software with the purpose of providing support and increased value in risk assessment. Three models are presented based on the concept of forest fire risk: forest fire structural hazard model that provides the assessment of the expected easiness that a fire has to spread in a certain area, a stochastic model that assesses the fire growth potential considering as potential ignition points critical elements of electric supply networks and a stochastic model that assesses the potential impact of forest fires on these infrastructures.

Keywords

Electric supply network, fire growth potential, hazard, risk assessment, wildfire analyst

INTRODUCTION

During the last decade the view of the importance to use simulation software to assess the behaviour and characteristics of disasters has been widely extended by emergency management agencies, by critical infrastructures companies as well as insurances companies. These tools provide support in the planning, prevention and mitigation of the damages caused by different types of large-scale hazards such as forest fires. The use of simulation tools for the assessment of the risk and consequences of forest fire for planning activities as well as decision-making helps to reduce the harmful consequences of fires. This translates directly into human safety and economic benefit which justifies the required investments and interventions to reduce in general the fire risk of a forested area. Besides, Electrical companies are particularly vulnerable to the effect of wildland fires as their electrical networks cross wide landscapes of forested land. For these companies, risk assessment is very valuable not only for identifying the potential damage and economical losses that a forest fire may cause on their power supply network and therefore their overall electrical service, but also, to assess the impact that a fire originated in their supply network may cause to the surrounding assets.

Aiming to provide a solution for these companies, the operational forest fire simulation tool Wildfire Analyst^{TM} (Ramírez, Monedero and Buckley, 2011) is being extended in the framework of the European R&D project PHAROS to include the operational forest fire risk assessment models described in this paper. In this regard, three different simulation models are presented, (i) a structural hazard model that provides the assessment of the expected easiness that a fire has to spread in a certain area, (ii) a stochastic model that assesses the growth potential of a forest fire considering as potential ignition points critical components of existing electric supply networks and (iii) a stochastic model that assesses the potential impact of forest fire on these critical infrastructures.

These models are being developed and implemented with the aim of achieving among other benefits, the increase of population safety, reduction of forest fire suppression activities costs, reduction of the forested areas impacted by forest fires as well as to reduce potential damages of forest fires to electric supply infrastructures.

CONCEPT OF RISK RELATED TO FOREST FIRES

The term Risk has been extensively used by the wildfire community but not always with the same meaning (Miller and Ager, 2013). Following the general risk notation, risk is assumed to be measured as the product of two main factors – (i) hazard, and (ii) vulnerability (ISDR, 2004; Finney 2005).

Following Scott, Thompson and Calkin (2013), hazard represents the potential of causing damage, hence applied to forest fires it has been considered as a function of – (i) the burn probability (likelihood) and (ii) the intensity of the fire (that can be translated by the variables that measure the intensity which are the flame length, Rate of Spread and fireline intensity). A forested area where fires are common and which vegetation types lead to high intense fires would have a high hazard.

The vulnerability is also composed of two variables – (i) the exposure, and (ii) the susceptibility. Exposure is the placement of a valuable asset in a hazardous environment and the susceptibility of an asset is how easily it is damaged by wildfires of different intensities. So:

Risk = hazard (intensity, probability) x vulnerability (exposure, susceptibility)

Relating this concept of forest fire risk with electric supply networks and according to the characteristics of these assets, they can be considered as - (i) the hazard source of the risk when considering that the forest fires are originated by these installations, (ii) the vulnerability component when considering that these assets can be affected by forest fires.

Furthermore, based on this conceptual approach, in the current work the “forest fire structural hazard” concept that is described in the following section has been considered as the intensity component of the risk formula presented before considering that the variables used for its calculation translate the intensity of a forest fire. At the same time, the “potential growth of forest fires based on electric supply networks” concept was assumed to be the probability component of the formula since it provides the probability of the spread of a fire originated by those infrastructures. Finally, the concept of “potential impact of forest fires on electric supply networks infrastructures” was considered as the vulnerability component of the presented risk equation when considering that these assets are vulnerable to forest fire.

Moreover, it is important to emphasise that the forest fire structural hazard is considered as a landscape component of the hazard which represents the intensity of the fire in a forested area. Being a landscape component of the hazard it disregards the influence of the existence or not of electric supply networks for the analysed region. In contrast the (i) concept of forest fire growth potential based on electric supply infrastructures and the (ii) concept of potential impact of forest fires on these infrastructures take into account the influence of electric lines networks as assets in forest fire risk, considering these assets as (i) source of hazard, i.e. assets as forest fire cause and for concept (ii) as vulnerable element, i.e. assets affected by forest fires.

FOREST FIRE STRUCTURAL HAZARD

This risk assessment model is a deterministic model that provides the calculation of the potential behaviour of the fire for a certain area. The forest fire structural hazard of an area represents graphically through different hazard levels the intrinsic easiness that a fire has to spread in that area also referred to as fire intensity. The calculation takes into account three different fire behaviour variables which are (i) the rate of spread of the fire (ROS), (ii) flame length and (iii) fireline intensity. The ROS is a variable of measurement of the speed at which the fire moves across a landscape, the fireline intensity measures the intensity of the fire in the burned area, whereas the flame length measures the height of the flame (Stacey, Gibson and Hedley, 2012). This simulation model provides the decision-maker with an overview of the most critical zones with regard to the potential behaviour of a forest fire in case of ignition in any location of the considered area.

The intrinsic easiness that a fire has to spread in a forested area depends on the fire flame length, fireline intensity and ROS which are calculated by making use of the semi-empirical fire spread equations from Rothermel (1972) and Albini (1976). This simulation model uses as inputs the topographic information of the terrain such as slope and aspect, the vegetation fuel models types and corresponding moisture contents as well as forecasted weather data taking into account the wind speed and direction, the air temperature, as well as the relative humidity.

Using as input the mentioned data, a standard simulation of the fire behaviour is carried out. The structural hazard of an area is calculated considering the results of three aforementioned forest fire behaviour variables. For obtaining the structural hazard the model performs a reclassification of the obtained values according to reviewed literature (Albini, 1976; Andrews, 2003; Delgado, 2008). Table 1 presents the reclassified values for each of the considered fire behaviour variables.

The structural hazard is obtained by the weighted sum of the three reclassified variables, considering a lower weight for the ROS since it is the parameter that characterises the agricultural fires, which are clearly the less dangerous type of fires that may occur. This type of fires are characterised by propagating in a fast way, presenting low flame intensity and are therefore easier to suppress. Hence, the structural hazard proposed for a synoptic condition is given by the following formula:

Fire structural hazard = Flame length + 0.5*ROS + Fireline intensity

The fire behaviour varies according to the forecasted weather conditions, taking into consideration that these affect the state of the existing fuels and hence the behaviour of the fire in the terrain. Finally, the results of the sum of the three physical parameters of the fire are then reclassified into five levels of values which represent the structural hazard levels of the fire as presented in Table 2.

Table 1. Reclassified values for flame length, rate of spread and fireline intensity variables

Class	Flame length (m)	Rate of Spread (m/min)	Fireline intensity (kw/m)	Value
Low	<1	<0,5	<346	1
Moderate	1-2,5	0,5-2	346-1730	2
High	2,5-3,5	2-33	1730-3460	3
Extreme	>3,5	>33	>3460	4

Table 2. Structural hazard levels

Structural hazard	Values of the sum
Low	<3
Moderate	3-4
High	5-6
Severe	7-8
Extreme	9-10

Based on the values presented in the previous table a raster output is created presenting to the user the structural hazard levels that range from "Low" to "Extreme". In Figure 1 is presented an example of the forest fire structural hazard output for a certain area in Spain.

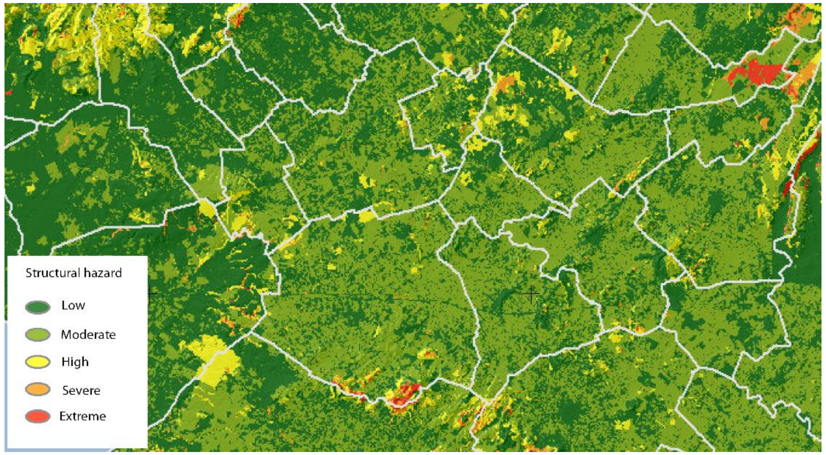

Figure 1. Example of calculation of structural hazard in an area of Spain

FOREST FIRE GROWTH POTENTIAL BASED ON ELECTRIC SUPPLY NETWORKS

This simulation model performs an assessment of the spread potential of the fire in a forested area having as basis potential ignition points of electric supply networks of a certain area. In general terms it can be considered as an assessment of the forest fire growth probability having as ignition source several points of those infrastructures. The model is able to model the factors of fire ignition as well as of fire propagation based on overhead power lines infrastructures.

The forest fire risk concept presented before characterises the risk of fire across a landscape disregarding the existence of a specific ignition point in that area. This approach being valid for planning purposes it does not address the specific requirements of ignitions caused by certain points or elements of the power supply networks also called as discrete ignition sources, nor takes into consideration the risk of fire related to these specific infrastructures components. Hence, an alternative approach has been taken to characterise forest fire, defined as Risk At Ignition Location (RAIL) by Scott, Thompson and Matthew (2015). The two main elements of a RAIL analysis are - the (i) ignition likelihood and the (ii) forest fire spread potential starting at a certain point of the electric network. These elements are analysed for every considered potential ignition location. These locations are assigned to certain components of the electric infrastructure such as transformers, fuses, and similar equipment that is considered potential elements with regard to the ignition of a fire.

Ignition likelihood

Thus, the ignition sources considered for this simulation model are elements that are part of the electrical transmission and distribution network. Several ignition categories have been defined and for each of these a ponderation percentage has been assigned. The ignition likelihood categories have been assigned according to a group of factors that influence the mentioned likelihood, including, among others: Height, density and species of trees surrounding the infrastructure; number of capacitors; number and type of fusing, number and type of switches; conductor size, age and number of splices noted; wind factor exposure to strong wind; vegetation fuel density in the surroundings of the electric supply network; other circuit issues from field and operating personnel.

Fire growth potential

The fire growth potential for fires with origin in electric supply infrastructures depends on the conditions of the terrain, the existing vegetation fuels as well as on the weather conditions of the areas surrounding the electrical installations. For the definition of this RAIL element the following fire environment factors are considered: type of vegetation fuel models; topography of the terrain; wind speed and direction; air temperature; relative humidity and fuel moisture.

The fire environment is formed by the conditions that influence the spread of the fire. As can be deduced from the presented list the fire spread model consumes spatial as well as temporal information about the fire environment to simulate the fire growth from a given ignition location for a certain period of time. The model makes use of the approach of the Monte Carlo simulation of fire spread (Carmel, Jahashan and Shoshany, 2008) to assess the fire spread potential taking into account the temporal variability of the fire environment. The Monte Carlo recursive algorithm runs hundreds to thousands of simulations for each considered potential ignition point. Following this approach the results are then compiled to obtain the values of fire growth potential also designated as burn probability. The simulations are performed based on the fire spread models (Rothermel, 1972; Albini, 1976) and time evolution model calculating for each simulation the spread of the fire in space and time (Finney, 2004).

Since the considered weather conditions significantly affect the modelling of the fire, this simulation model takes into account the weather conditions (based for instance on a statistical analysis of historical weather data). The weather conditions that are considered are the wind speed, wind direction and the moisture values of the live and dead vegetation fuels.

Once all simulations are completed for all considered ignition source locations, the results of these are combined to derive a burn probability output that depicts the areas where fire will spread from all the considered ignition source locations, i.e. it represents the total fire growth potential. It is important to emphasize that the burn probability does not directly depend on the density or number of possible ignition sources, but rather on the existing landscape and weather conditions. Accordingly, numerous fires may not result in significant spread if the landscape conditions do not back up the rapid spread of the fire. A pilot assessment has been carried out in Southern California assuming a random distribution of 5000 ignitions points that represent the supply network. Each ignition source has been simulated 150 times with different weather conditions and then all simulations have been combined to obtain the burn probability map (see Figure 2) that represents the number of times that a fire has reached a given cell.

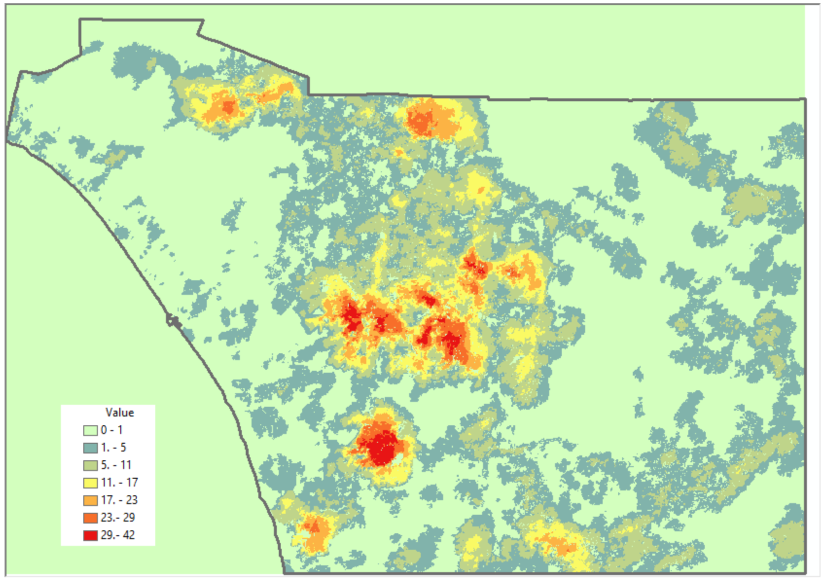

Figure 2. Example of burn probability for a given weather condition and considered ignition sources

POTENTIAL IMPACT OF FOREST FIRES ON ELECTRIC SUPPLY NETWORKS

This simulation model performs an assessment of the potential impact that a forested area may present to the existing electric supply networks in case of forest fire. It evaluates which are the areas surrounding the electric infrastructures that present more susceptibility and therefore allows identifying potential areas in need of intervention, being it at the level of electric supply networks equipment or at the level of the forested area with the purpose to protect these installations and assure power supply continuity.

The methodology of this simulation model follows the same strategy of the model of growth potential of forest fires based on electric supply networks described before. Two main aspects differentiate the current model from the previous one.

The first consists on the fact that for this model the power supply network is considered to be the vulnerable asset contrary to what occurs in the other model. Furthermore, all the points of the critical infrastructure are considered to have the same influence in the calculation of the exposure considering that if the fire damages any of the points of the asset, as consequence, all of the infrastructure components will be damaged as well impeding the continuity of power supply. Hence, no affectation likelihood is needed to be considered for this simulation model. The second aspect consists on the fact that this model uses the evacuation time mode model (Cova, 2004) instead of the standard fire spread models to calculate in each simulation the time a hypothetical fire starting at a given cell of the domain would take to reach any of the points of the electric network. As in the previous model, this simulation mode makes use of the approach of the Monte Carlo simulation of fire spread (Carmel et al., 2008) performing hundreds to thousands of simulations for each point of the asset. Every performed simulation provides an x-hour fireshed around the asset (Ramirez et al., 2011). The results are then compiled to obtain the potential impact of the fire on the electric supply networks infrastructures. The results are then represented graphically to the user through a raster file.

CONCLUSION

Forest fire risk assessments are increasingly important for forest fire management and planning. They constitute a valuable work for aiding decision-makers in taking decisions about necessary forest mass mitigation interventions to reduce forest fire risk. The basis of the analysis of this type of risk has been defined many years ago, nevertheless the current work in enhancing existing forest fire behaviour models aim to increase the value that simulation tools represent for forest fire managers and other decision-makers. The development and implementation of such models in the forest fire simulator Wildfire Analyst™ aim to contribute to this objective. Hence in this current work by making use of the definition of forest fire risk three simulation models have been presented. The deterministic structural hazard model, takes into account fire behaviour variables, topographic data as well as weather data, the generated output provides the decision-makers with an output that allows them to easily evaluate which are the most critical areas with regard to the fire behaviour in case of ignition at any point of the area. The stochastic fire growth potential model provides information about the growth potential of the fire considering critical ignition points of elements of the electric supply network allowing the decision-maker to assess which are the valuable assets that require protection and which measures should be taken to reduce that risk. Finally the stochastic model that evaluates the impact of forest fire on power supply networks allows taking enhanced decision about which elements of the critical asset or which forest areas surrounding need intervention. In the follow-up work, opportunities exist to extend the presented risk assessment models also to other types of critical infrastructures besides power supply networks that may be also a potential source of ignition. Furthermore the incorporation of economic data shall be considered to allow an economic impact analysis and risk reduction. This may be achieved by combining the results obtained by the presented forest fire risk assessment models with parcel assessor data for a certain region such as ownership parcels, commodity agriculture among other datasets.

REFERENCES

1. Albini, F. (1976) Estimating wildfire behavior and effects". Intermountain Forest and Range Experiment Station General Technical Report INT-GTR-30. (Ogden, UT).
2. Andrews, P. and Rothermel, R. (1982) Charts for interpreting wildland fire behavior characteristics. USDA Forest Service, Gen. Tech. Report INT131, 1982, pp. 21.
3. Carmel, Y., Paz, S., Jahashan F. and Shoshany, M. (2008) Assessing fire risk using Monte Carlo simulations of fire spread, Elsevier.
4. Cova, T., Dennison, P. and Kim, T. (2004) Setting wildfire evacuation trigger points using fire spread modeling and GIS.
5. Delgado, F. (2008) Análisis del incendio forestal: planificación de la extinción. Aifema, ISBN 8461221508, 9788461221509.
6. Finney MA (2005) The challenge of quantitative risk assessment for wildland fire. For Ecol Manag. 211:97–108.
7. Finney, M. (2004) FARSITE: Fire Area Simulator – Model Development and Evaluation.

8. ISDR (2004) Living with risk: A global review of disaster reduction initiatives. United Nations publication. Vol. I: ISBN 92-1-101064-0, pp16, 36.
9. Miller, C. and Ager, A. (2013) A review of recent advances in risk analysis for wildfire management. International Journal of Wildland Fire 2013, 22, 1-14.
10. Ramirez, J., Monedero, S. and Buckley, D., (2011) New approaches in fire simulations analysis with Wildfire Analyst^{TM}. 5th International Wildland Fire Conference. Sun City, South Africa. DOI: 10.13140/2.1.2045.7766.
11. Rothermel, R. (1972) A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service, Intermountain Forest and Range Experiment Station Research Paper INT-115. (Ogden, UT).
12. Scott, J.H., Thompson, M.P. and Calkin, D.E. (2013) A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.pp83.
13. Scott, J.H. and Thompson, M.P. (2015) Emerging concepts in wildfire risk assessment and management. In IAWF-AFE 2014 Large Wildfires Conference Proceedings (in press)
14. Stacey, R., Gibson, S. and Hedley, P. (2012) European Glossary for wildfires and forest fires. EUFOFINET Project.