

A Forest Fire Simulation Tool for Economic Planning in Fire Suppression Management Models: An Application of the Arcar-Cardin Strategic Model¹

Francisco Rodriguez y Silvae²

Abstract

Simulation of dynamic fire spread behavior of forest fires provides important information for decision-making. Specific programs facilitate the option of analyzing the energetic characteristics and spatial developments of fire spread, as well as the potential results. By simulating strategic attack and suppression plans through resource positioning to control and extinguish forest fire, decisions can be validated before their execution. In economic analysis terms, the simulation offers the possibility of valuing the cost of different suppression strategies and preventive planning associated with vegetation management, such as qualitative and spatial change of fuel models. The simulation model, Arcar-Cardin, is a capable tool for defense programs against forest fires. The organization and structure of the program at the user level and the procedure plan for personnel is presented in this paper, as well as the program's practical application to help prevent and extinguish forest fires.

Introduction

Technological developments in the field of data processing have permitted the elaboration of simulation programs of great versatility and usefulness, offering a multitude of alternatives as tools in decision-making. These specialized simulation programs should be capable of facilitating information about the dynamic behavioral forecasts of fires that evolve in different forest ecosystems.

In 1989 the first version of a forest fires simulation program, designated Cardin (Martinez Millan 1991, Martinez Millan and others 1996), was developed. The simulation program has evolved and improved as it has been used by the organizations that specialize in detecting and preventing forest fires. A conversion program has been developed, Arcar41, that transforms the ARC/INFO³ data in geographic information systems (GIS) into the file formats required by Cardin to simulate forest fires. This program includes a set of enforceable components in turbo-basic and files of macros written in SML language of ARC/INFO. Initially, a specific program was designed to be used with Cardin, known as "cartographic digitalizations" (Digicar); however, because GIS has more advanced functions and information already elaborated under its data processing structures, a conversion program that uses both GIS and the Cardin simulation program helped us to obtain a savings in cost, effort, and time. The simulation program uses the 13 fuel models of the BEHAVE system used by the USDA Forest Service (Anderson 1982) by adapting them to the Mediterranean ecosystems. The advance of the fire is reproduced as a function of the digital terrain model and meteorological characteristics. Adjustments to local conditions causes the fire perimeter shape to change.

Strategic Planning of the Arcar-Cardin Model to Simulate Forest Fire Behavior

The development of the fire is verified in the Arcar-Cardin program on a zone of 400 by 400 pixels, which consists of four map modules, each 20 by 20 cm,

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Policy, and Planning: Bottom Lines, April 5-9, 1999, San Diego, California.

²Associate Professor, Forestry School, University of Cordoba, and Chief of the Forest Fires Department, Regional Ministry of Environment of Andalusia. Eritana, no. 2, 2,41071 Seville, Spain; e-mail: frysilva@arrakis.es.

³Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

identified with the universal transverse mercator (UTM) geographics reticle. The simulation begins by establishing an ignition area or ignition line that uses a set of pixels. For each pixel, a value of maximum slope and direction is determined via mathematical calculations based on the digital terrain model.

The rate of spread in the address (a) is determined with the following equation:

$$V\alpha = (V_0 + V \cos(\alpha - a))Fw$$

in which ($V\alpha$) represents the spread rates for a given fuel, with zero wind and horizontal area; (a) represents the angle constituted by the pending maximum address with the north of the UTM reticle; (V_0) represents the spread sheet and the joint effects of the wind and slope; and (Fw) represents an adjustment factor of the burned area that is determined by the quotient between the broad maximum calculations obtained from BEHAVE and from the theoretical figure based on the spread model from the Cardin program.

The program operates by using a disk-operating system (DOS) and is programmed in turbo-basic. The simulation of fire spread is accomplished from analysis of the times that would delay the fire's advancement in each one of the cells contiguous to the pixel already burned. Before this analysis, if the program shows that the cells have already burned, they are not included in the analysis. These pixels can be studied by the spread model from different roads, depending on the origin of the combustion evolution. This is translated in the appearance of an angle (w), which develops differently. The pixels that are found active in each time (t) define the profile of perimeter of the fire developing.

Modular Structure of the Program

The program begins with a principal menu displayed horizontally in the upper part of the screen, offering users different components or options that can be added to the simulation and that are displayed vertically on the screen. The program can establish a new simulation, use the last developed, or use a stored file in a directory of previous simulations. This capability allows an itemized analysis of possibilities to extinguish a fire. All simulations can be saved to a stored directory file established by the user. This permits an itemized analysis of the extinction of the fire. All accomplished simulations can be saved in the place indicated by the user.

Before starting a simulation, it is necessary to define a virtual space where the program can calculate temporary files that will then become permanent files as the steps progress in the simulation. After the option is selected to create the virtual space of the simulation, the user can adjust the conditions of the environment by defining the colors that will correspond to the fuel models, which establishes a framework in which the user can develop and store the simulation.

The "initial user" option contains the command "colors," which can be used to assign and change the colors initially assigned to each one of the polygons of the different fuel models. The "monitor" option controls the value of the diagonal of the monitor in inches, which calculates the scale of the graph. The "directory" option allows the user to access the directories of previous simulations stored in the program.

The main menu includes the set of characteristics that a user needs to establish a simulation. These characteristics include "map" options of several operative map modules and a "name" command that establishes the simulation. The UTM reticle can be coordinated and digitally manipulated directly on the screen, and various components, such as soil, flammability, and cartography, can be selected to define the initial components of the simulation.

A "parameters" module incorporates the data associated with local characteristics, such as the "wind" command, which includes direction and speed that can be measured down to 6 m on the area. The "humidity" command

assigns the level of dampness, and live or dead fuels can be classified by their geometric characteristics. In addition, by using this procedure the dampness of the dead fuels can be obtained as a set of calculations based on data such as the date, meteorological effects, and the area and state of the vegetation. The "cover" command assigns the degree of protection from the flammable front of the wind. The "residence" command establishes the possible set of flames and embers assigned to the different fuel models. This command simulates the combustion process as a result of windspeeds.

The fourth module contains the specified instructions to execute the simulation. Before the module is executed, alternative options can be selected that either correspond to the automatic defaults of the program, or the user can stop the simulation manually at time intervals that are entered into the simulation program.

The program offers the possibility of using the cursor to introduce barriers, such as fireproof fronts, to the dynamics of the fire spread. The "report" command obtains data and information that the user specifies on any cell of the screen, such as UTM coordinate, slope, aspect, vegetation cover, fuel models, speed and wind direction, access time of the fire to the cell, and maximum spread rate in the cell with respect to combatting the fire. This information can be altered by the user to reduce the dangerous characteristics of the fire spread.

Arcar-Cardin is capable of generating the simulation effects to intervene, control, and extinguish the fire. The program is extremely useful in its ability to measure different fire management strategies and the equipment resources needed to implement the strategies. To simulate the suppression actions of infrastructures, firefighting resources, yields, and communications, data chips can be created and imported from the database by using the program "GFUEGO" (file:*.DBF) that can function independently of the Arcar-Cardin program.

The fire fighting resources include firefighters (transported by land or air [helicopter]), fire engines, machinery for land movement, amphibious air tankers, air tankers, and fire fighting helicopters. It is possible to use the entire set of resources in the simulation because of the real yields for the resources. The program uses this information in the cells by establishing the corresponding values of the individual rates for each type of resource.

Arcar-Cardin incorporates a relative module into images that can be set in two or three dimensions. If the user wishes to use two dimensions, zones of 200 by 200 pixels are established for flame length, directions, residence of the flame, wind maps, fireline intensity of the flame front, heat by unit area, and rate of simulated spread.

Applications of the Program

The Arcar-Cardin simulation program has a number of practical applications that attest to its usefulness in fire management. First, the program is useful because it can generate knowledge of potential fire behavior forecasts, which allows fire managers to adapt fire attack plans so that they are more successful.

Second, the program is also helpful to fire managers because it can help identify defense infrastructures (fuelbreak) and transform fuel models so that a forest can be managed to prevent forest fire. Arcar-Cardin tests and confirms preventive silvicultural strategies that have been used to hinder forest fires.

Third, Arcar-Cardin can be used in post-analysis of a fire. It can reconstruct the fire behavior and verify results obtained by the different attack plans to extinguish the fire. This feature can be used in final reports on the nature of a fire and the evaluation of the effectiveness of the resources used. This information can be used to set up training courses on fire behavior and fire suppression.

The use of the program within a fire planning area is directed from a Regional Command Center. Given the large amount of geographic information that establishes the work environment (digital geographic models, forest fuel models, infrastructures, etc.), it is necessary to have adequate computer storage to manipulate the necessary information in the simulations.

The great advantage of Arcar-Cardin is its ability to simulate the fire behavior of an active fire with or without resource intervention. The results of different strategies can be analyzed before mobilizing actual resources to extinguish a fire. The selection of various options and resources in a simulation is a very efficient tool for fire management.

The selection of the resources for an efficient initial or extended attack plan is established by following these procedures:

- *Initial Phase:* Visual analysis of the digital terrain model, fuel models, uses of the soil and of positioning of the infrastructures, roads, and fire prevention.

Determination of the complications that the forest area presents to the control and suppression of the fire (suppression index).

Simulation of the spread without the intervention of resources by obtaining the spatial structure of the advance and development of the forest fire. Elaboration of alternative spread dynamics by using different meteorological situations that could be representative of a zone in different hours of the day.

Obtainment of the surface perimeters affected under different meteorological conditions and of topographic influence.

- *Final Phase:* Checking the data base of the available resources in the proximity of the fire.

Distribution of the resources in the fire according to the initial attack plan.

Intervention of simulated resources compared to the real fireline production rates to determine the correspondence of the simulation results to the actual results.

Determination that the resource equipment provided in the simulation was the most effective containment strategy to hinder the dynamic spread of the forest fire.

The simulation of an attack and control of fire by using different resources results in cost estimates of the different scenarios. The economic analysis provides information on those bottom line resources that can hinder the dynamic spread of fire, and it provides important information about the costs of different resources used to fight a fire.

The data obtained from the economic analysis of fighting a fire is a valuable tool for evaluating the effects of a fire on a particular area. This analysis provides information for evaluating the effectiveness of an attack plan and different contingency plans to combat fires.

Arcar-Cardin can provide information about fire behavior that might evolve as a result of the different combinations of fire attack and the resources used. To develop a record of the economic impact of the suppression activities, it is necessary to keep track of the value of certain parameters associated with all resource used. These parameters are:

- Containment rate of spread (CRS): This parameter is obtained by comparing the relationship between the time it takes a specific resource to stop the fire rate of spread, in a specific zone of the perimeter, compared to the spread rate without the same resource intervention.
- Opening defense lines (fireline production rates, FPR): This parameter collects data for each individual resource about the linear meters of line constructed by unit of time.
- Hourly cost of the resource (CHR/s): This parameter is a calculation of the surface area that a resource is capable of protecting.

- Down times (DT) within period of anticipated performance: This parameter collects the total time that a resource is unavailable as a result of breakdowns, short moments of rest, travel times, fuel reloads, etc.

The results obtained from the detailed analysis of combinations of the four parameters allows fire managers to more efficiently select the resources needed to combat a fire. Throughout the simulation the effectiveness of alternative firefighting equipment can be tested, which offers greater efficiency in the actual control of a fire.

Real Application of the Simulations

The simulation program is currently used in Andalusia, Spain, by the Regional Command Center to Fight Forest Fires. The methods used to implement the results of simulations of the Arcar-Cardin program follow this sequence:

- Detection of the fire.
- Communication from the Provincial Command Center to the Regional Command Center.
- Dispatch of the initial attack group.
- Use of a global positioning system (GPS) to obtain geographical coordinates and to evaluate the situation.
- Establishment of the parameters needed to accomplish a simulation (fuel models, topography, infrastructures of fire prevention).
- Creation of the work modules of 200 by 200 pixels.
- Input of the initial data required to develop the simulation.
- Development of the simulation without activating the suppression module.
- Development of the simulation with the firefighting equipment needed to fight the fire based on economic information.
- Elaboration of the conclusions of the accomplished simulations. Shipment of the performance plans simulated to the command post of the fire and to the Local Command Center.
- Determination of the economic value of the intervening resources by compiling a final report after the control of the fire that compares the differences between the operations prescribed by the simulation and the succesful use of the work equipment.

The results obtained from a simulation can be used to build a database in which the surface area of a fire is allowed to spread without the inclusion of the suppression resources. The purpose of this function is to simulate an actual fire to obtain the surface area after the control of the fire. The quotient between both surfaces determines the rate of control of fire spread. This parameter facilitates information about controlling a fire in similar, real environmental conditions. This historical knowledge provides fire managers with a set of effective resources for controlling and extinguishing a forest fire.

In Andalusia, Spain, the program Arcar-Cardin is being used as a tool to simulate prescribed burns before they are implemented. The results provide information about the parameters of fire behavior, facilitating statistics on the value registered in each cell in the rate of spread, flame length, heat by unit of area, and fireline intensity of the front. This information can be used to determine the number and types of resources necessary to meet safety criteria. These simulation results also provide fire managers with the amount of funds needed to prevent and extinguish forest fires.

References

- Anderson, H.E. 1982. **Aids to determining fuel models for estimating fire behavior.** National Wildfire Coordinating Group. Gen. Tech. Rep. INT-122.
- Martínez Millán, J. 1991. **Cardin, un sistema para la simulación de la propagación de incendios forestales.** Investigación Agraria Sistemas y Recursos Forestales; 121-133.
- Martínez Millán, J.; Condes, S.; Martos, J. 1996. **Simulación de la propagación de incendios forestales integrada en un GIS.** Proceedings of the joint European conference and exhibition on geographical information. Vol. 2. Barcelona, Spain; 1307-1315.