Information System for the Optimal Management of Fire Brigades in Wildfires

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Introduction

The consequences of a wildfire may be predicted using models that simulate its spread and take into account the spatio-temporal action of firefighters.

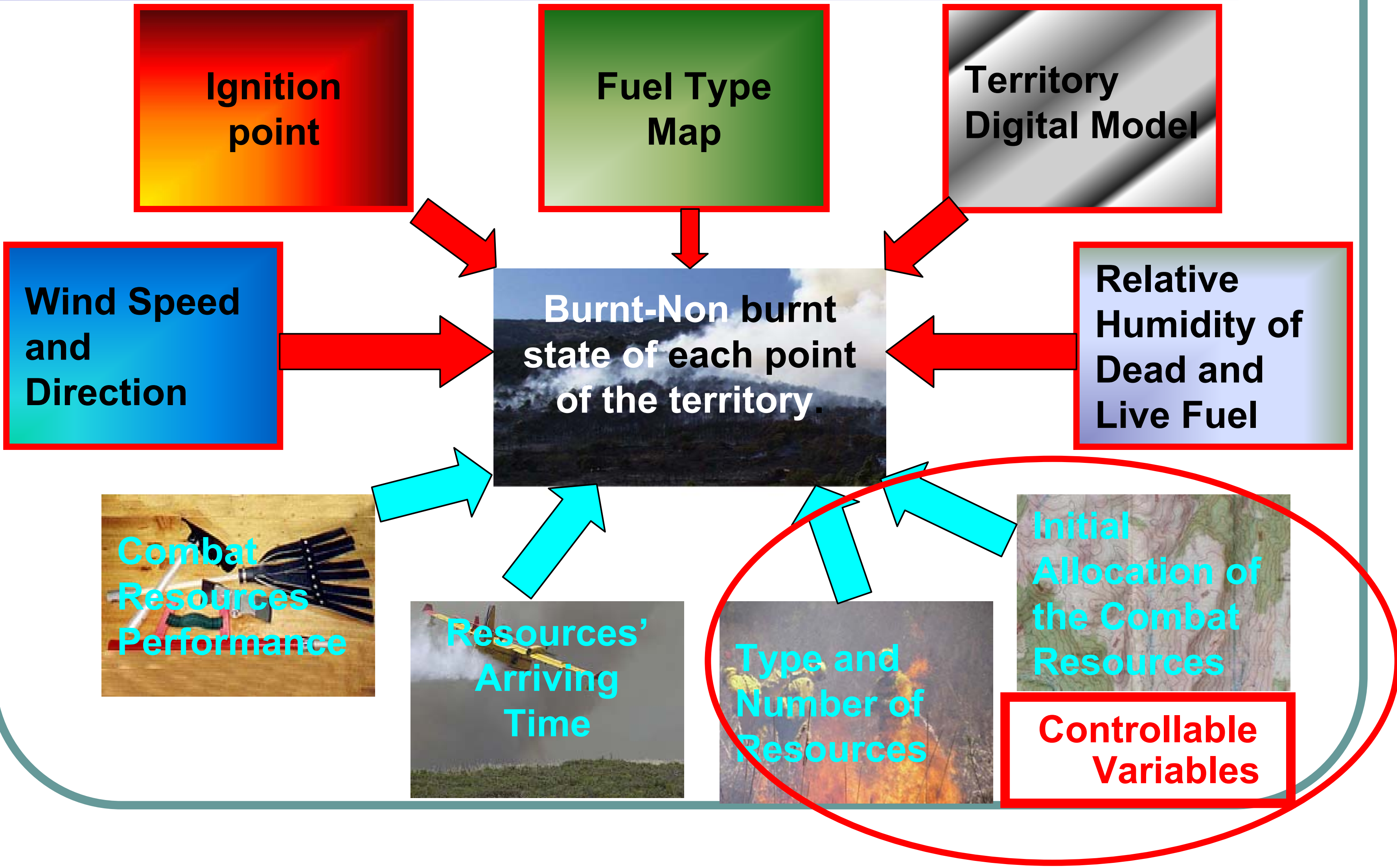
Introduction

- Deterministic models are usually utilized to predict the spread of the fire (Dupuy 1991).
- The most widely used BEHAVE (Andrews 1986), that applies the model developed by Rothermel and Burgan (1984).
- In the present investigation, an adaptation of the CARDIN model (Martínez Millán and others 1994) was adopted to estimate the spread of the fire.

Introduction

The factors that determine the burnt surface in a wild fire are the following:

Introduction



Objective*

The aim of this application system is to optimize the resource management so as the value of the burnt surface is minimized, using simulation models that predict the behavior of a fire and the resources' combat.

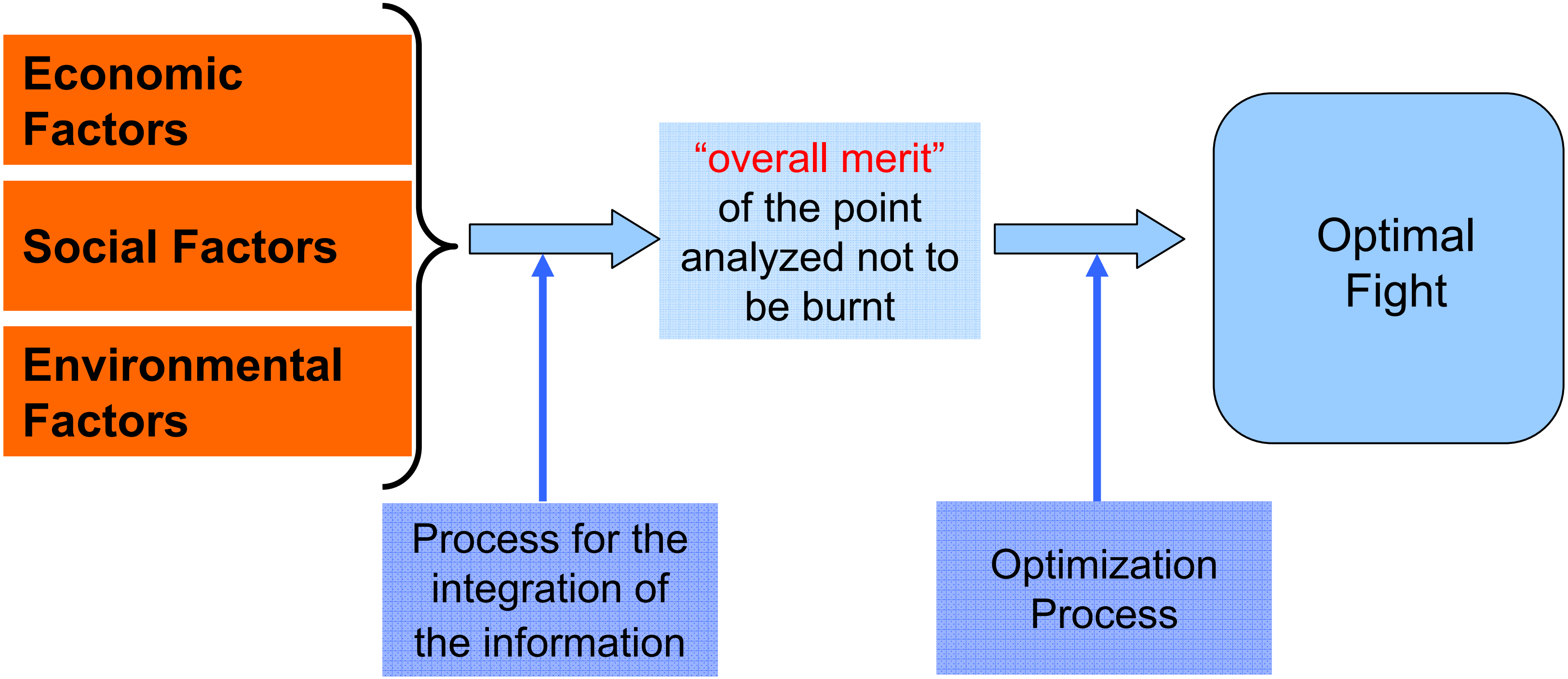
*further information of this work can be consulted in:

- Martin-Fernández, S. et al, 2002, Environmental Management Vol. 30, No. 3, pp. 352–364.
- Or sending an email to susana.martin@upm.es

Metodology

The best combat strategy needs to be defined using the available resources and information. We calculated the burnt surface value by means of data **integration models**. These allow one integrated value to be assigned to each point of the territory. This value represents the **“overall merit”** of the point analyzed. The higher this value is, the higher priority for fire defense.

Metodology


Economic Factors
Social Factors
Environmental Factors
"overall merit" of the point analyzed not to be burnt
Optimal Fight
Process for the integration of the information
Optimization Process

Metodology: Objective Function

The objective function is the following:

$$\Delta F_{\Omega}(\vec{X}(t), t_f) = \int_{\Omega} f(\Psi(\vec{X}(t), t_f))dw - F_0$$

Where:

Ω is the geographical area under investigation,

X(t) is the crews' fight at time t. **Decision Variable.**

$\Psi(X(t),t_f)$ is the fire spread.

t_f is the time when the value of the forest is calculated.

F_0 is the integrated value of the forest before the fire.

Metodology: Objective Function

Consequently, the problem that needs to be resolved is

$$\min y = \Delta F_{\Omega}(X(t), t_f) \ X \in \Theta$$

where Θ is the set of possible resource-management strategies corresponding to the available resources.

$$If \ \Delta F_{\Omega}(X_0(t), t_f) \leq \Delta F_{\Omega}(X(t), t_f) \ \forall X \in \Theta \ then$$

X_0 is the optimum strategy looked for.

Methodology

The chaotic nature of fire means that the optimum strategy corresponds to a limited time period δt, (15-20) minutes.

Methodology: Optimization Method

The Bayesian procedures involve defining a decision rule over a set of samples Z, in which each $y_{i,n}$ is obtained by the application of simulation models,

$Z = [(x_{n,l}, y_{n,l}), \ldots (x_{n,i}, y_{n,i}), \ldots (x_{n,p}, y_{n,p})]$,

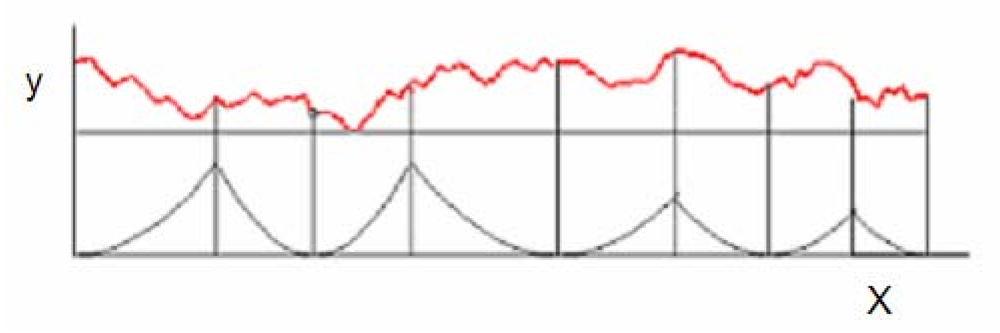
where $y_{n,i}$ is the loss of overall value of the study area that occurs as a consequence of the fire and of the resource-management strategy adopted.

Methodology: Optimization Method

Mockus' Method (1989)

Iterative process that converges to the optimum. The objective function can be expressed as a combination of functions defined on contiguous intervals of the variable X. Mockus' simplification, limits the search for the next solution, x_{p1}, to the boundaries of the contiguous intervals X_i. The value of x_k corresponding to the lowest y_k determines the next sample value x_{p1}.

$$f(x) = f_h(x) \quad \forall x \in \left[X_h, X_{h+1}\right] con\ h = 1,\ldots,n$$



Methodology: Optimization Method

The large number of combinations from assigning *m* resources of different types, arriving at each location at a different time, that can be fought in two different ways

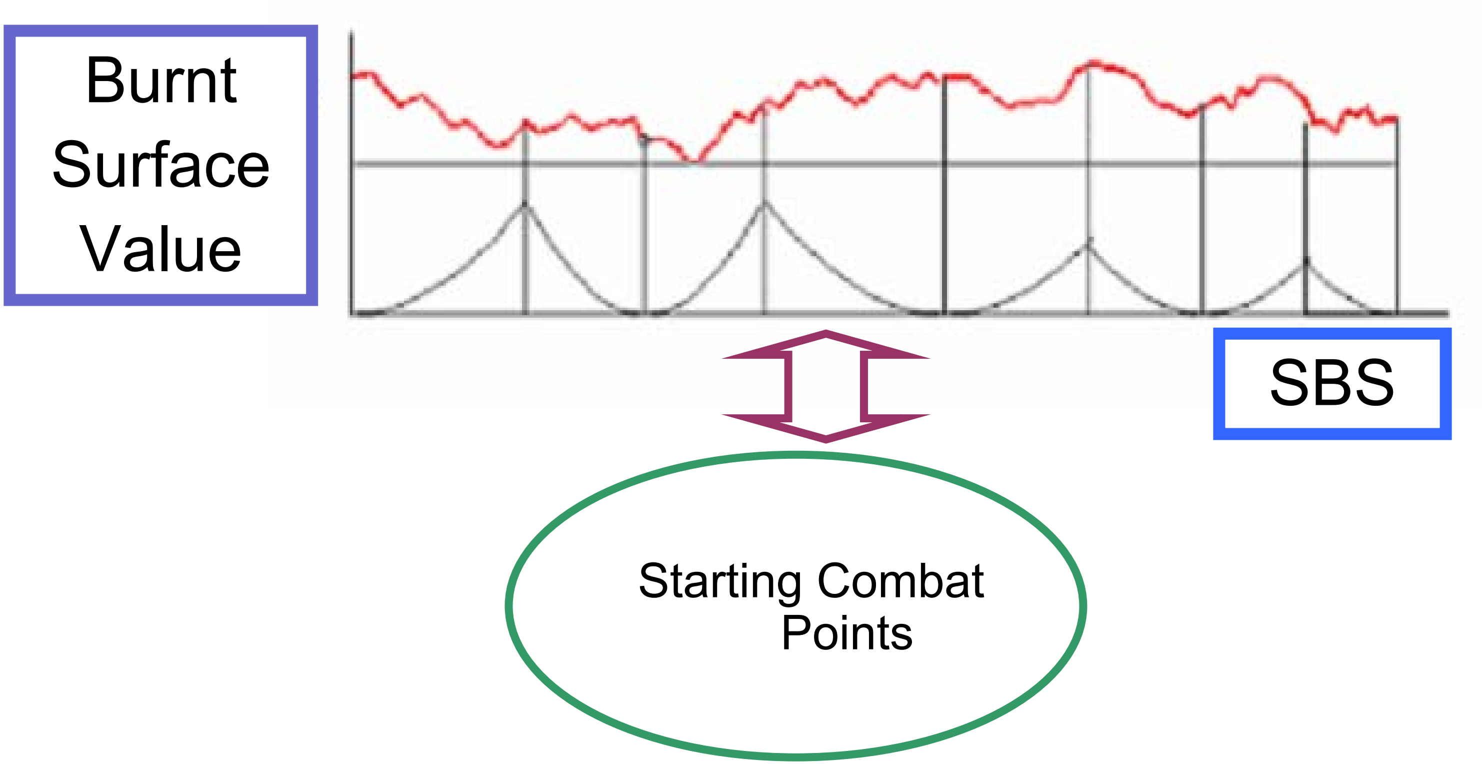
↓ *Reduces*

Mockus procedure efficiency

↓ *One-dimensional variable is defined*

The simplified burnt surface (SBS)

Methodology: Optimization Method



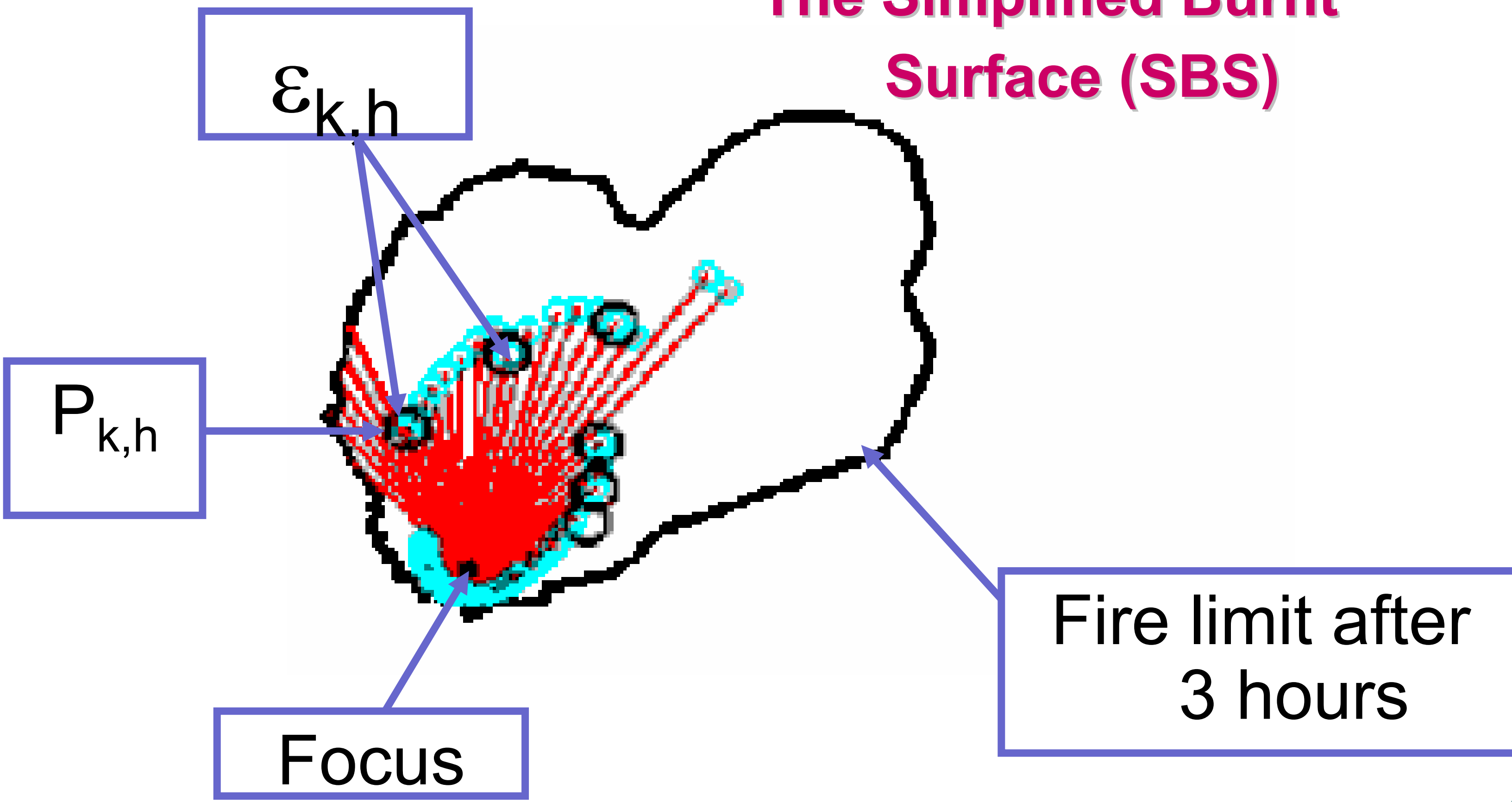
Methodology: Optimization Method

The SBS is characterized by:

1. The number of possible points of start of combat are reduced to the points that belong to *N* radii computed from the focus.
2. When the fire reaches the possible points of start of combat $P_{k,h}$, the burnt area is substituted by the Cullman ellipse defined so that its area is equivalent to the burnt area at a given time.
3. From each possible point of start of combat $P_{k,h}$, (point *h* in radius *k*) the resources perform an elliptical combat according to a Cullman ellipse $\varepsilon_{k,h}$.
4. For each fire-fighting resource, a map of resource arrival time from its initial allocation to the fire is obtained using another simulation model.

Methodology: Optimization Method

The Simplified Burnt Surface (SBS)



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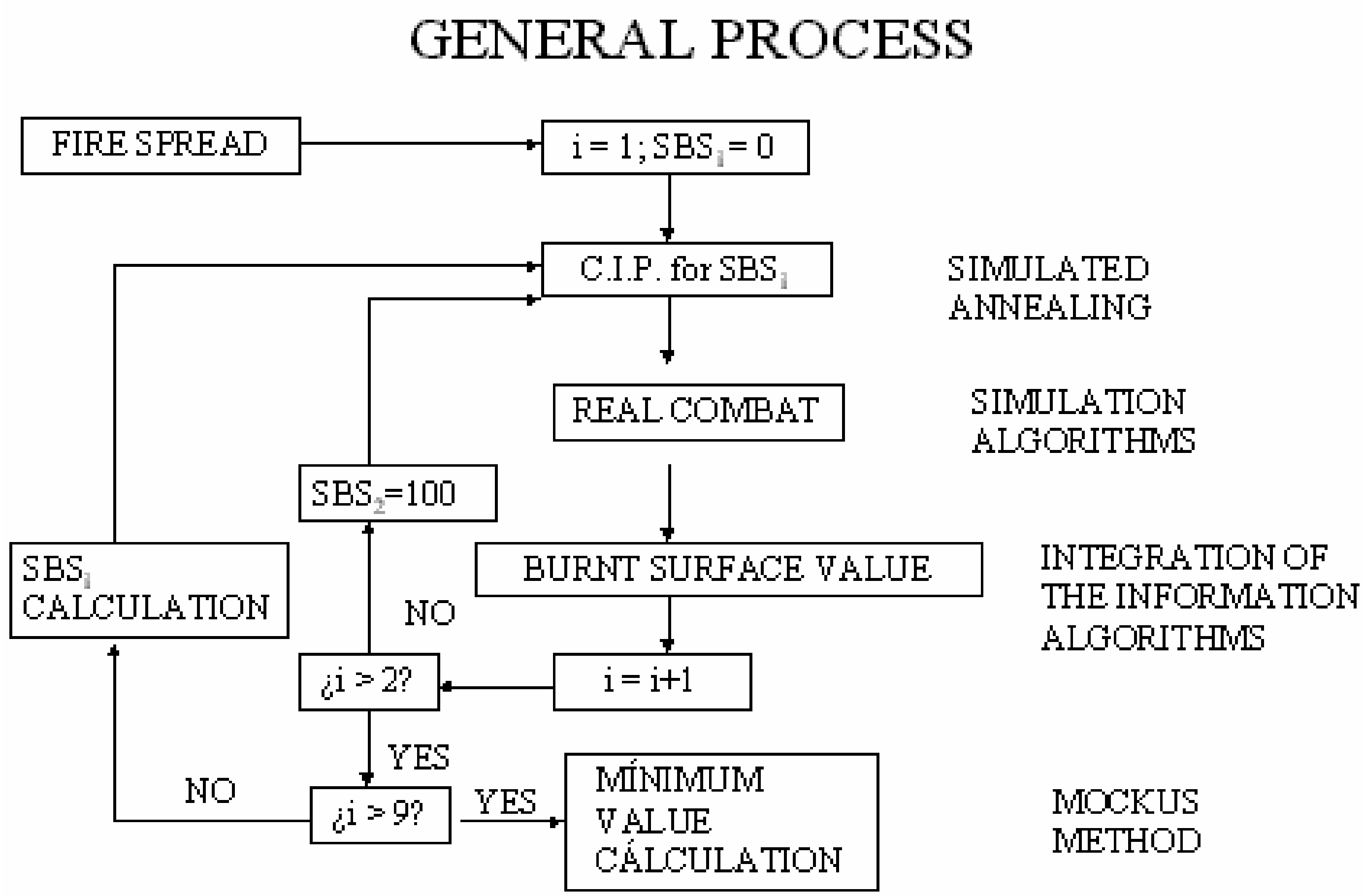
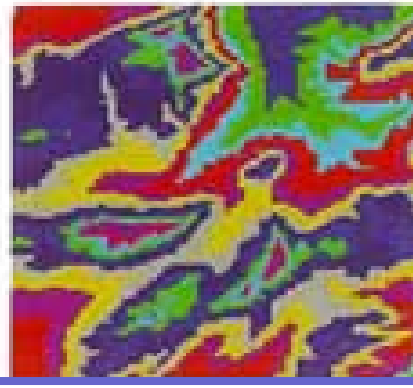
The Process

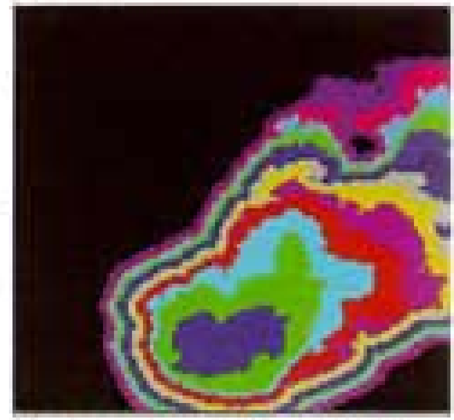

GENERAL PROCESS
FIRE SPREAD
i = 1; SBS1 = 0
C.I.P. for SBS1
SIMULATED ANNEALING
REAL COMBAT
SIMULATION ALGORITHMS
SBS2=100
SBS1 CALCULATION
BURNT SURFACE VALUE
INTEGRATION OF THE INFORMATION ALGORITHMS
NO
¿i > 2?
i = i+1
YES
NO
¿i > 9?
YES
MÍNIMUM VALUE CÁLCULATION
MOCKUS METHOD

The Process



Territory Digital Model

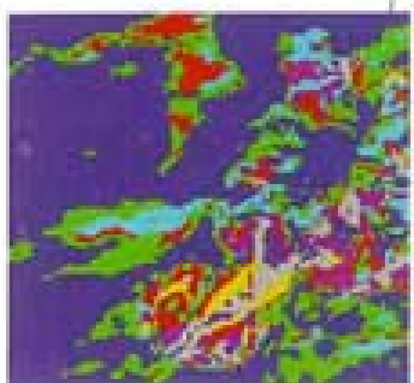
Wind speed and direction,
Relative humidity of live fuel,
Relative humidity of dead fuel,



Fire Spread Map

1

FIRE SPREAD MAP



Fuel Map

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The Process

Simulated annealing is applied in this step as the combinatorial optimization method (Geman and Geman 1984, Cerny 1982, Kirpatrick and others 1982, etc.). Starting from an initial SBS, this value is changed until the looked-for SBS is reached.

2

STARTING COMBAT POINTS SBS IS 0%.

The Process

2

STARTING COMBAT POINTS SBS IS 0%.

For a given initial allocation of resources, x_{h1}, corresponding to a particular value of the resource-management decisional variable, the probability that the resource *k* will change position from *j* to *i*, where the possible starting point of fire-fighting is c_k, with the initial positions of the other resources, remaining unaltered, $-c_{k.}$, is expressed by:

$$P\left[x_{h,i} = c_k ; \lambda(\varepsilon_i) = \bar{c}_k\right] = \frac{1}{z} \exp\{\frac{1}{T} U\left[x_{h,i} = c_k ; \lambda(\varepsilon_i) = \bar{c}_k\right]\}$$

Z is a standardization constant, *T* an adequate constant (in the original Gibbs model the *cooling temperature).*

The Process

Direct combat: extinguishing resources are placed at the perimeter of the fire and the combat path coincides with the fire front.

Indirect combat: extinguishing resources make a firebreak in specific areas.

The resources start their combat in the points obtained in step 2.

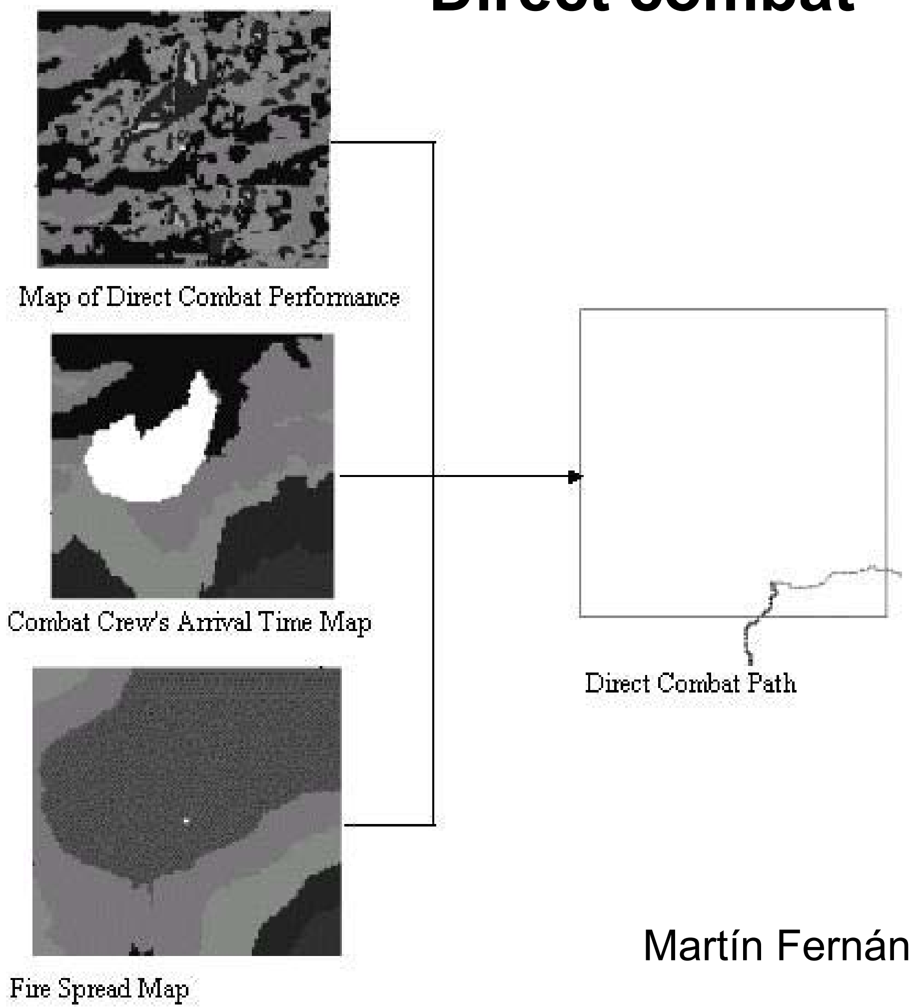
3

REAL BURNT SURFACE

The Process

3
REAL BURNT SURFACE

Direct combat



Direct combat is performed manually by combat crews. by fire pumps, or by the action of planes or helicopters.

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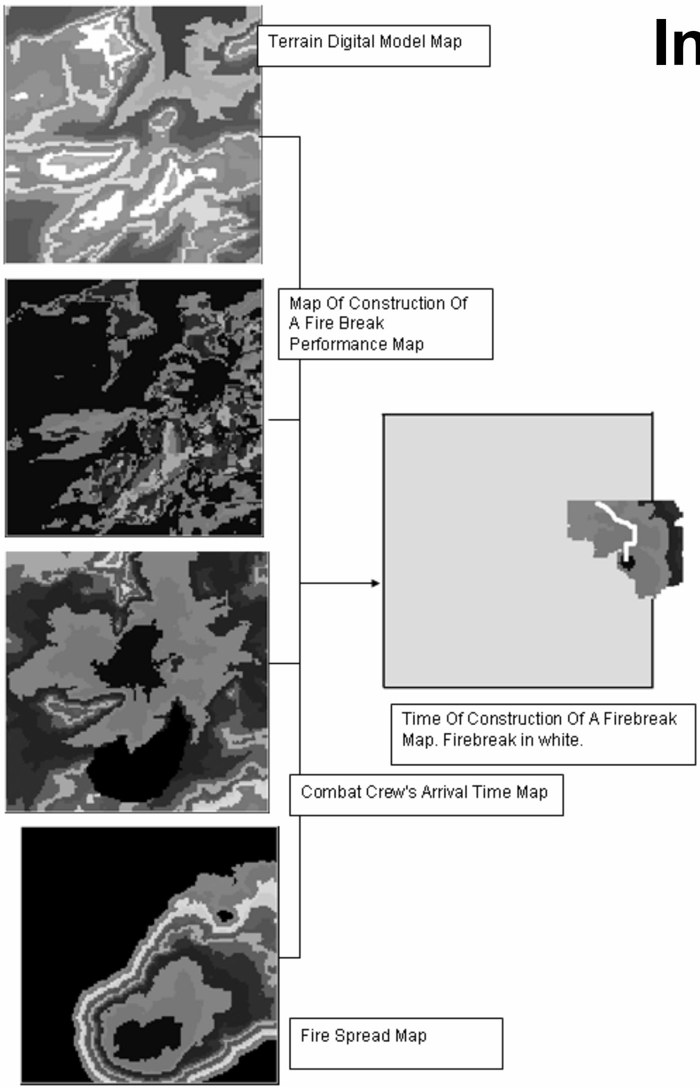
The Process

3
REAL BURNT SURFACE

Indirect combat



Indirect attack is conducted by crews or by mechanical means using bulldozers, excavators, etc.

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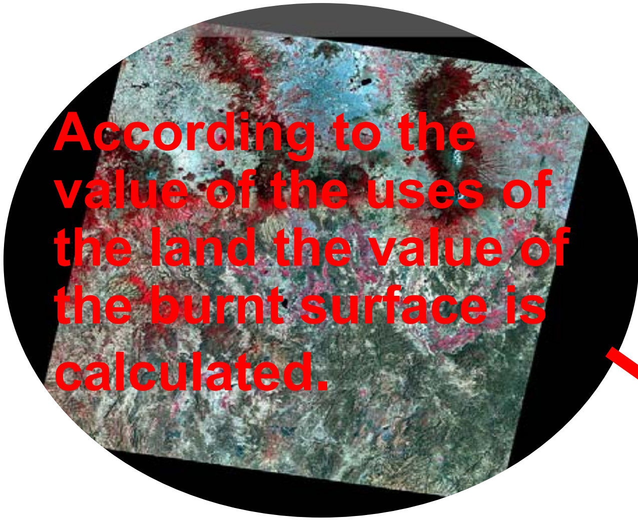
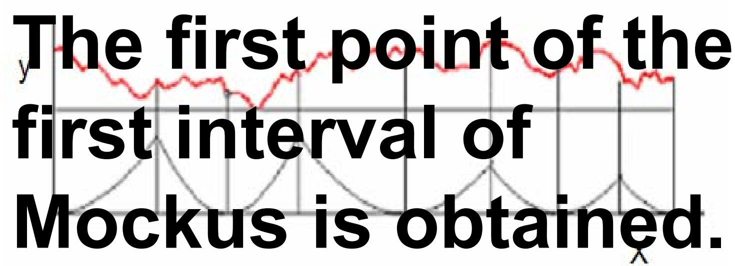
The Process





4

CALCULATING BURNT SURFACE VALUE

The Process

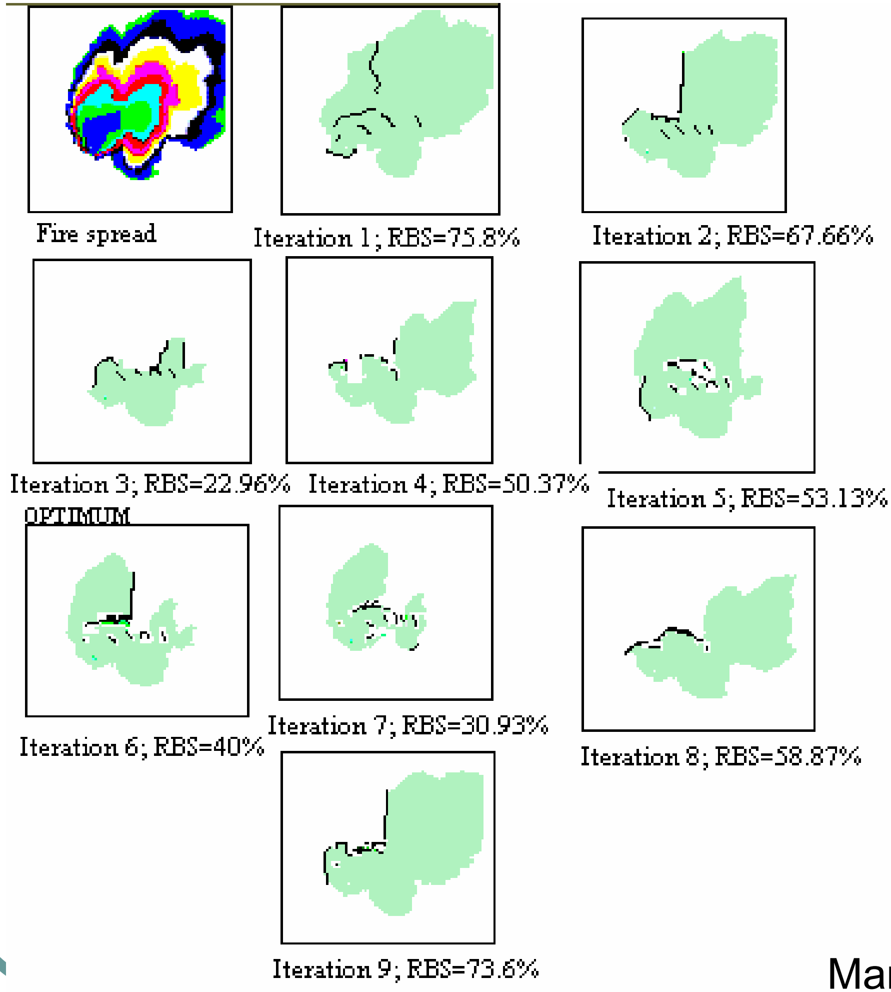
Second iteration: The starting combat points of the resources are obtained when the SBS is 100%. Then steps 2, 3, 4 are followed.

Next iterations: The value of the next SBS is obtained applying Mockus's method. Then steps 2,3,4 are calculated.

5

FOLLOWING ITERATIONS

Results of the iterative process



Real burnt surfaces of an area of 144 ha, in the Guadarrama Mountains, Madrid,

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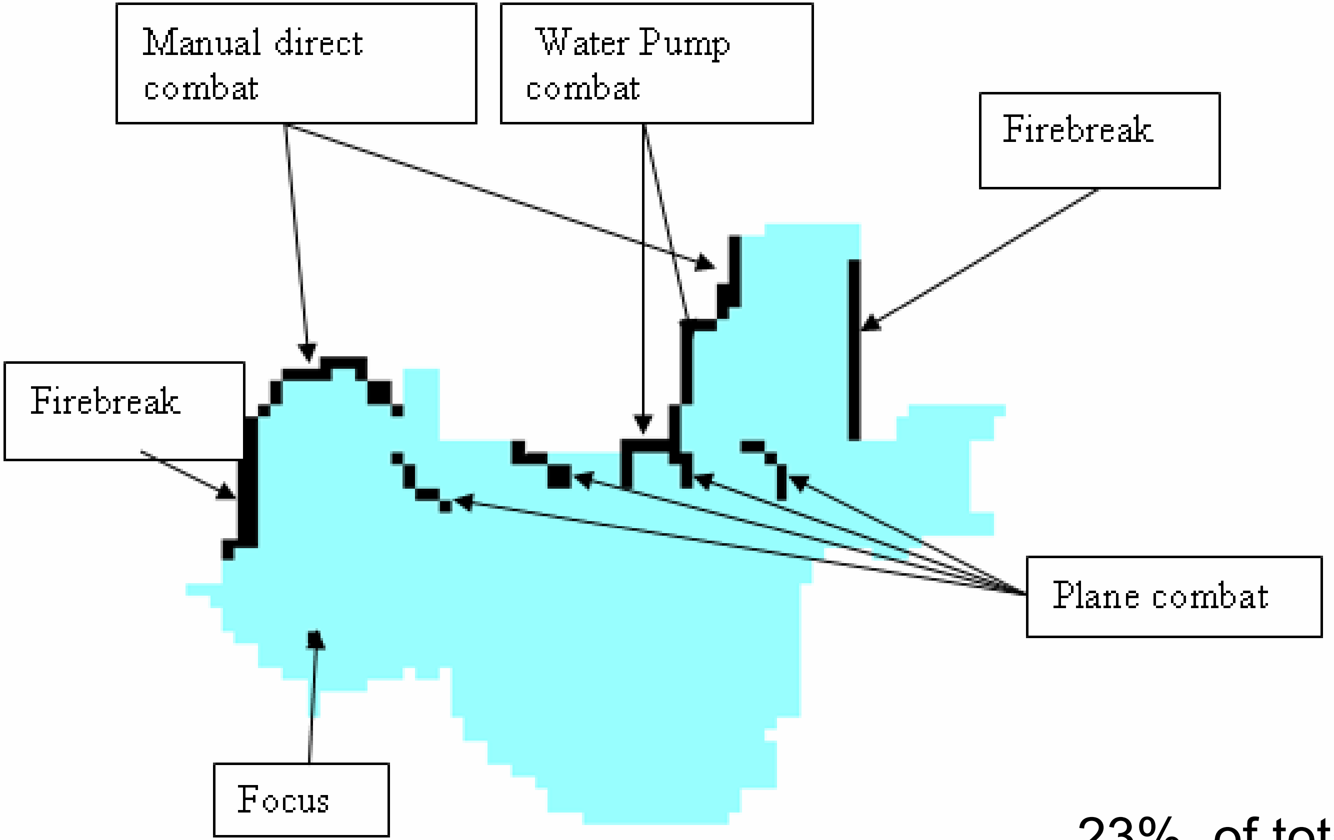
The Optimum



23% of total area burnt

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