Structural and operational design of a decision support system aiming at forest fire risk management in WUI

Paolo Fiorucci[1], Francesco Gaetani[1], Riccardo Minciardi[1,2]

[1]CIMA - Centro di Ricerca Interuniversitario in Monitoraggio Ambientale
via Cadorna, 7- 17100 Savona, Italy. Phone: +390192302712
[2]DIST – Dipartimento di Informatica, Sistemistica e Telematica – Università di Genova
via Opera Pia, 13 - 16145 Genova, Italy. Phone +39010353-2804, Fax -2154
e-mail: Name.Surname@unige.it

Keywords: dynamic modeling, dead fine fuel moisture, fire management, risk assessment.

Abstract

In this paper, a methodology based on system modelling and optimization is developed to assess forest fire risk over a regional area paying special attention to Wildland Urban Interface. To this end, a forest fuel moisture model and a propagation model are developed, in order to obtain a dynamic evaluation of the risk. On the basis pf the risk values over the whole area considered, it is possible to apply a resource allocation policy. The objective of such an allocation may be twofold. In the planning phase, a suitable set of infrastructures (roads, water supplies, etc.) capable of mitigating the fire risk over the considered area is considered. Then, resource allocation can take place on the basis of the solution of an optimisation problem, whose objective is the risk minimization in WUI taking into account the constraints corresponding to the available economical resources, and those related to environmental impact assessment. Instead, in the preventive phase, means and crews are re-allocated on the basis of the risk (forecast on the basis of available real-time information), in order to successfully fight initially spread fires.

Introduction

Among natural risks, forest fire is one of the most remarkable in Mediterranean areas especially as regards the frequency of the events, and the complexity of the organization needed to manage such a risk, and to definitely fight an active forest fires. Actually, although the ignition of a fire in a forest area is in the almost totality of the cases responsibility of man, and therefore is not recognizable as a natural event, its propagation is determined by the territorial and meteorological characteristics. On the basis of such considerations, it is nearly impossible to speak of ignition forecast. On the counterpart, it is important to analyze the inducing factors of fires, and to provide evaluations and indications about the consequences that a fire could yield over the territory in case of a successful ignition.

Climate and vegetation make Mediterranean basin frequently affected by large forest fires. In fact, winter average temperatures higher than the continental ones, irregular rainfalls, generally very abundant and concentrate in few months of winter, coupled with drought summer seasons, and frequent windy days, make the vegetation particularly vulnerable to ignitions. In addition, it is worth to observe that in the last decades a dramatic change in social and economical behaviour has made an increasing number of hectares of woodlands be directly in contact with urban settlements. The simultaneous presence of different activities or land use, such as pasturage and woods, or urban settlements and agriculture, makes the probability of fire occurrence very high. In addition, a generalized lack of urban planning and the increase of urban sprawl phenomena, expose to higher risk a growing number of citizens and hectare of woodlands.

Forest management and wildfire prevention are directly connected with the phases, which anticipate, correspond to, and follow a forest fire. The interventions able to modify the vegetational structure, or the water supply and logistic infrastructures, pertain to the planning and prevention level, whereas the interventions defined in order to realize an effective contrast to fires, taking into account the available resources and the current scenarios, pertain to the pre-operational management and the real-time management level, respectively. Finally, the interventions on already burnt parcel, the updating of the vegetation database, the acquisition of information about the wildfire, and the restoration of the original conditions of natural biotypes, are generally grouped within the term of restoration interventions, and often coincide with the first phase of territorial planning procedure.

Forest fire emergencies are characterized by a great demand of intervention, concentrate only in some periods of the year. On the counterpart, a relative lack of available resources imposes to take the best choice as regards the mobilization of resources in the pre-operative phase, and when fires are signalled, on the on the strategy to cope with active fires. Of course, the effectiveness of the extinguishing actions is heavily dependent on the timeliness of resource displacement. On the other hand, the use of such resources generally is characterized by high operational costs.

The evaluation of the forest fire damage and costs is a Forest Service specific task, and may be carried out on the basis of the value of the destroyed wood volume and on the hypothetical restoration cost. However, such evaluations generally are not adequate, since they ignore the environmental damage, that is the alterations of the vegetational, faunal and hydrological equilibriums existing before the fire occurrences. In this respect, the adoption of tools able to appraise the forest fire risk as regards the planning, and the pre-operational phase, may be extremely advantageous.

The proposed approach

The proposed approach is based on the interaction of five independent modules, namely: 1) the fuel moisture model; 2) the propagation model; 3) the risk assessment module; 4) the planning module, 5) the preventive resource allocation module, all interacting with external databases able to provide the required data needed for the overall system definition.

A regular grid of k=1,..,K cells discretizes the considered area. As the purpose is that of determining forest fire risk for each cell k, the rate of spread and the linear intensity that a fire could assume (in case of a successful ignition) are determined. Such an information is obtained through a propagation model, which is not used to evaluate the dynamic of a single fire but to evaluate the physical characteristic that a fire could attain, in each cell *k*, on the basis of the variables locally influencing ignition and fire propagation. To this end, it is assumed that the available fuel for ignition corresponds only to dead fine fuel load. Such an assumption is justified by the fact that fire ignition and behaviour is highly correlated with dead fuel moisture and uncorrelated with live fuel moisture (Marsden-Smedley and Catchpole, 1995). The live fuel load is introduced only to evaluate the linear intensity, and seasonal variability of the lower heating value is taken into account.

The proposed approach is based on the use of a geographical information system that allows selecting the settlements exposed to forest fire risk within a WUI. Namely, to each cell belonging to the WUI a cost is associated that takes into account the different uses and activities of each different kind of settlement. Thus, taking into account the effectiveness of intervention, on the basis of logistic information and the present displacement of the available means, it is possible to assess the forest fire risk in the considered WUI.

The fuel moisture model

As mentioned in the previous section, the fuel moisture model has the function of representing the dynamics of the dead fine fuel moisture. More specifically, for each cell *k* over the considered region, a single model is considered, which does not interact with the models of the other cells, as no fire propagation is represented.

Let $u_k(t)$ represent the dead fine fuel moisture at cell *k*, at time instant *t*.
The basic assumption about the evolution over time of the above quantity is that it is governed by the following simple differential equation

$$\frac{du_k(t)}{dt} = K_1\, 1(t) - K_2\, u_k(t) \qquad (1)$$

The reason for this choice is that the solution of (1) has an asymptotic behaviour determined only by the ratio (K_1 / K_2), namely

$$u_k(t) = \frac{K_2 \cdot u_k(0) - K_1}{K_2}\, e^{-K_2 t}\, 1(t) + \frac{K_1}{K_2}\, 1(t) \qquad (2)$$

Of course, the asymptotic value (K_1 / K_2) is independent from the initial state $u_k(0)$ and the transient behaviour is decaying (increasing) if $u_k(0) > (K_1 / K_2)$ $(u_k(0) < (K_1 / K_2))$. Observe that the “time constant” characterizing the speed at which the transient term in the r.h.s. of (2) vanishes, is $1/K_2$.

Actually, note that the solution (2) of eq. (1) is correct only in the assumption of time-invariance of coefficients K_1 and K_2, which however, as it will be discussed below, are in fact time-varying, as they depend on a set of meteorological variables, Thus, the use of solution (2) is sensible only whenever the dynamics of model (1) (which is characterized by the time constant $(1/ K_2)$) is considerably slower than meteorological dynamics (which determine the variation of K_1 and K_2). However discretization of (1) is in any case allowed, even though K_1 and K_2 are significantly time-varying. For this reason, hereafter the dependence of such coefficients on time (and on cell k) will be explicitly represented.

It is reasonable to assume that coefficients $K_{1,k}(t)$ and $K_{2,k}(t)$ are actually functions of meteorological variables $p_k(t)$, $w_k(t)$, $\square_k(t)$, $\square_k(t)$, that is the cumulated rain [m], the wind [m/s, rad], the relative humidity [%], and the air temperature [K] respectively. Actually, instead of trying to model such a dependence through thermodynamic considerations, it seems preferable to propose a semi-physical model in which such dependences can be adequately accounted for. To this end, first of all, note that the asymptotic value ($K_{1,k}(t)/K_{2,k}(t)$) can be dichotomically expressed as a function of $p_k(t)$, namely

$$\frac{K_{1,k}(t)}{K_{2,k}(t)} = e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}} \qquad \text{if } p_k(t) \le p^* \qquad (3a)$$

$$\frac{K_{1,k}(t)}{K_{2,k}(t)} = \beta_1 \qquad \text{if } p_k(t) > p^* \qquad (3b)$$

where, of course, α_i (i=1,..,4), β_i are constants having suitable dimensions.

Note that (3a) holds in absence of significant rainfall (in the last time interval), whereas (3b) holds whenever such a rainfall cannot be neglected. Of course, it must be

$$\beta_1 > e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}} \qquad (4)$$

for any possible value of $w_k(t)$, $\rho_k(t)$, and $\tau_k(t)$. Besides, note that the dependence of the r.h.s. of (3a) on $\square_k(t)$ is justified as the higher the value of $\square_k(t)$ the higher the asymptotic value of $u_k(t)$[1]. Finally, note that the fact that the r.h.s. of (3b) is independent of $p_k(t)$ is justified by the assumption that the asymptotic values of the fuel moisture is independent of the rainfall intensity. The fuel moisture is uncorrelated with temperature and humidity in case of rain. The rains bring the fuel moisture condition at the fibre saturation point that is greater than 35% (Cheney, 1981).
As regards the dependency of $K_{2,k}(t)$ from meteorological variables, recalling that $1/K_{2,k}(t)$ is the time constant which (in time-invariant meteorological conditions) characterizes the transient behaviour represented in (2), the following model can be proposed[2]

$$K_{2,k}(t) = e^{sign\left[u_k(t) - e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}}\right]\left[\alpha_5\tau_k(t)+\alpha_6 w_k(t)\right]} step\left[p^* - p_k(t)\right] + \max\left\{p_k(t) - p^*, 0\right\}\beta_2 \qquad (5)$$

where again constants having suitable dimensions have been introduced.

The structure of the r.h.s. of (5) may be justified as follow. First of all, note that $K_{2,k}(t)$ represents the "speed" of the transient term in (2). Then, the first term in the r.h.s. of (5)

[1] Note that such an asymptotic values is actually only "potential", as it is achieved only when meteorological conditions are time-invariant.
[2] Function step[x] is defined as equal to 1 if $x \ge 0$ and equal to 0 otherwise.
Function sign[x] is defined as equal to 1 if $x>0$ and equal to 1 when $x<0$. It is undefined for $x=0$.

Close this chapter

applies in absence of significant rainfall and thus $K_{2,k}(t)$ represents the speed of the drying (resp., moistening) process when $u_k(t) > e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}}$ (resp., $u_k(t) < e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}}$)[3]. Clearly, the dependence proposed in (5) makes so that a high value of temperature and wind intensity favours drying but hampers moistening, as it is consistent with experience. Instead, the second term in the r.h.s. of (5) applies in presence of significant rainfall, and provides a linear dependence of the moistening speed on the rainfall intensity. Of course, from (3a), (3b) it turns out

$$K_{1,k}(t) = K_{2,k}(t)\left\{ step\left[p^* - p_k(t)\right] e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}} + \left(1 - step\left[p^* - p_k(t)\right]\right)\beta_1 \right\} \qquad (6)$$

or even, taking into account (5),

$$K_{1,k}(t) = e^{\left\{ sign\left[u_k(t) - e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}}\right]\left[\alpha_5\tau_k(t)+\alpha_6 w_k(t)\right] + e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}} \right\}} step\left[p^* - p_k(t)\right] + \qquad (7)$$
$$+\left(p_k(t) - p^*\right)\beta_1\beta_2\left(1 - step\left[p^* - p_k(t)\right]\right)$$

At this point, having discussed and justified (1), and having presented a reasonable model is represent the dependency of the coefficients appearing in (1) on the meteorological variables, it is possible to introduce the discretized version of (1), which is actually the one implemented in the developed software package. Namely, in discrete time, it is possible to write

$$u_k(t+1) = u_k(t)\left[1 + T\,K_{2,k}(t)\right] + T\,K_{1,k}(t) \qquad (8)$$

where T is the length of the discretization interval, and the time variable t is now an integer number.

The propagation model

As mentioned in Section 2, the purpose of the propagation model is that of providing a measure of the hazardousness, for each cell in the considered area.

Essentially, the dynamic information that such a model makes use of is that related to meteorological variables, and that provided by the fuel moisture model, which has been introduced in the previous section. In the same time, the propagation model makes use of orographical information, and of information related to vegetation (kind and density per m^2), again referred to the considered cells. The vegetational information (live fuel) may be considered as a “static” one – i.e., time-invariant – as concerns the development of the present model. In the development of the model under concern, the same reasoning lines proposed by Drouet (1974), as regards the definition of a forest fire

---

[3] Note that when $u_k(t) = e^{\frac{\rho_k(t)+\alpha_1}{\alpha_2+\alpha_3\tau_k(t)+\alpha_4 w_k(t)}} = \frac{K_{1,k}(t)}{K_{2,k}(t)}$ the value of $K_{2,k}(t)$ is irrelevant since there is no transient, as it appears from (2).

propagation model, will be followed. Recall, however that, in the present paper, we are not properly interested in a fire propagation model; instead, we are interest in determining a quantitative evolution of the hazardousness over the whole considered region. Such hazardousness is related to the “initial spread” behaviour of a potential fire after an accidental or deliberate ignition. The starting point for building of the model is the *nominal rate of spread* $v_{0,k}$, which is a constant quantity and refers to standard conditions as regards the temperature and the fuel moisture, in absence of wind and within a perfectly flat orography. Such standard conditions are represented by 20°C for air temperature and total absence of fuel moisture. In general, $v_{0,k}$ depends on cell index k, because in general nominal rate of spread is different for each kind of fuel. The propagation speed $v_{0,k}$ has to be modified as follows, in order to obtain the *potential rate of spread*

$$v_k(t) = v_{0,k}\ Z_k(t)\, W_k(t) \left[s_k + 2 \left(\frac{1 + s_k \cos\theta_k}{2} \right)^{1+\varepsilon\, s_k} \right] \tag{9}$$

where

- $Z_k(t)$ is the (multiplicative) correction (adimensional) due to the difference of the actual temperature, at time t and in cell k, with respect to the standard temperature assumed as the reference one;
- $W_k(t)$ is the (multiplicative) correction (adimensional) due to the presence of wind;
- the (adimensional) term in square brackets in the r.h.s. of (9) takes into account the (average) slope s_k of cell k and the angle θ_k between wind (average) direction and cell aspect relative to true North;
- ε is a parameter having dimension equal to the inverse of a speed.

The term $Z_k(t)$ can be structured as follows

$$Z_k(t) = \gamma_1\, e^{\gamma_2\left[\tau_k(t) - \tau_{0,k}\right]\left(1 + \frac{(1-\chi_k(t))}{\gamma_3}\right)} \tag{10}$$

where γ_1, γ□, γ□, are constants having suitable dimensions, and:

- .$\tau_{0,k}$, is the average (seasonal) temperature in cell k;
- χ□(t), is the total cloud cover of cell k at time t; χ□(t) is an adimensional factor belonging to the interval [0, 1], which can be directly measured or forecast by a meteorological model.

The term $W_k(t)$ can be structured as follows

$$W_k(t) = \left\{ 1 + \delta_1 \left[\delta_2 + \tanh + \left[\frac{w_k(t)}{\delta_3} - \delta_4 \right] \right] \right\} \left[1 - \frac{w_k(t)}{\delta_5} \right] \tag{11}$$

where parameters □$_1$,..., □□assume values such that $W_k(t) = 1$ when wind speed $w_k(t)$ is equal to zero, and assume maximum value (with zero derivative with respect to $w_k(t)$) when $w_k(t)$ = 70 km/h. Clearly, the structure of (11) may be justified on the basis of empirical evidence, at least over the regions of interest.
Finally, as regards the third multiplicative correction term in (9) (i.e., the one in square brackets), it can be noted that, for given s_k, it attains its minimum when θ_k = 180° (i.e.,

when the prevailing wind direction coincides with the maximum steepness direction of the considered cell). This is in accordance with experience that evidence that wind blowing in the same direction of on ascending slope favours the spread of a fire.
Having introduced the model to evaluate the potential rate of spread $v_k(t)$ it is now necessary to introduce a model to take into account the information relevant to vegetation density and moisture in cell *k*.
To this end, let us first recall that, as already pointed out in Section 2, in the proposed approach only the dead fine fuel moisture content is assumed to depend on the meteorological dynamics at the time scale considered for fire hazardousness evaluation. Such dependence has been detailed in the previous paragraph, through the introduction of the (dead fine) fuel moisture model. Instead, the moisture of live fuel is assumed as independent of meteorological conditions (and dependent only on the season and the vegetation in the considered cell).
A first way by which vegetational information is taken into account is that of evaluating the adimensional term $V_k(t)$ defined as:

$$V_k(t) = \frac{LHV_k^0(t)}{HHV_k^0} \tag{12}$$

where:

- HHV_k^0 [kJ/kg] is the *higher heating value* of the fuel (based on the prevailing species composition) in cell *k*;
- $LHV_k^0(t)$ is the *lower heating value* of the dead fine fuel in cell *k*, which takes into account dead fine fuel moisture $u_k(t)$, and is given by

  $$LHV_k^0(t) = HHV_k^0(t)[1 - u_k(t)] - Q\,u_k(t) \tag{13}$$

  being *Q* the *latent heat of vaporization* equal to 2448 kJ/kg.

Then, in the proposed model, it is assumed that a fire can actually start, when it is actually ignited in cell *k,* only if the dead fine fuel moisture content is smaller than a threshold value u^*. Thus

$$v_k^s(t) = v_k(t)\,V_k(t)\,step\left[u^* - u_k(t)\right] \tag{14}$$

If conditions (14) are fulfilled, then it makes sense to evaluate the (potential) surface fire spread at cell *k*, namely $v_k^s(t)$. The lower heating value of live fuel can be determined, analogously to (13), as

$$LHV_k^1(t) = HHV_k^1(t)\left[1 - u_k^1(t)\right] - Q\,u_k^1(t) \tag{15}$$

where u_k^1 [adimensional] is the moisture of live fuel at cell *k*, which is assumed to be independent of meteorological conditions, and thus of time *t* (apart from dependence on seasonal conditions, which is always understood in the proposed model). Then, on the base of Byram equation (1959) , it is possible to determine the fire linear intensity, that is:

Close this chapter

$$I_k^s(t) = v_k^s(t) \sum_{i=0}^{1} LHV_k^i \; \delta_k^i \qquad (16)$$

where $\delta_k^{0(1)}$ [kg/m^2] is the density of dead fuel (live fuel), for the considered season.

Note that in this paper it is assumed that the initial spread of a fire is always independent of the live fuel, whose contribution is taken into account only in the determination of fire linear intensity.

Risk assessment and mitigation

The values of linear intensity $I_k^s(t)$, defined for each cell k =1,..,N, and for each time instant t=1,..,T, aggregated in time and space, allow to estimate the fire risk over the considered area. Besides, a risk function can be introduced, in order to estimate the impact that the (expected) hazard can produce on the set of objects and relationships composing the territorial system namely

$$R_k(t) = F\left(I_k^s(t), c_k^i, \zeta_k\right) \qquad \text{for } k = 1,..,N, \text{ and } t=0,..,T\text{-}1 \qquad (17)$$

where the value (or cost) of the territorial element c_k^i, placed in cell k and belonging to class i, is obtained as a function of the monetary value of the element, or by the value of the service provided to the community by the considered object. Thus, to each different class of territorial elements, a weighting coefficient is associated, $c_k^i \in [0, 1]$, in order to define the total cost of the element on the cell k. The sum for k=1,..K, over all the classes i, has null value if no element is present and, on the other hand reaches a maximum value, equal to one, if all the considered classes are present in the cell.

The vulnerability ζ_k is introduced with the purpose of measuring the *strength* of the relationships among intensity I_k and physical, functional or systemic characteristic of cell k. The analysis of the fire propagation dynamics allows to express some considerations as regards the vulnerability evaluation, and therefore the risk to which the territory exposed in case of emergency. Forest fires vulnerability cannot be defined merely by a (non linear) relationship between the stress solicitation and the effects on the exposed target. Forest fires dynamics is comparable to extinguishing dynamics and, therefore the physical vulnerability of the elements must be considered as a function of extinguishing action. In addition, vulnerability is assumed to be a function of the intervention efficiency, defined in terms of available resources (weighted by the distance to the cell) that can cope with a fire in case of an emergency or patrol the cell in pre-operative phase. In urban areas, fuel load is generally negligible and, therefore, the hazard results very low or null. Thus, aiming at evaluating the risk of the territorial elements, they have been buffered by a zone perimeter, whose depth is a function of their typology or class. In this way, it is possible to define, for each of them, a safety zone, in which it is assumed that the presence of a fire can determine a potential (temporary) loss of functionality or, in severe risk cases, can produce a physical or structural damage.

In the planning phase, optimal decision techniques must be used in order to determine the optimal resource allocation on the whole territory, taking into account the expected risk, and the technical and economical constraints. In a preventive (pre-operative) phase, referring to a suitable defined time interval (e.g., 24-48 hours), it is necessary, on the basis of the risk forecast, to reallocate resources able to patrol the territory and intervene promptly, in order to successfully fight initially spread fires (Fiorucci *et al.*, 2002).

The objective of the planning phase can be that of minimizing the risk on the whole territory mitigating the effects that the presence of a fire may have on human activities, natural environment and land use. The planning phase must pay a special attention to WUI, where the peripheral urban zones are spaced out into productive agricultural surfaces or in abandoned areas, set to direct contact with the woodlands, producing serious hazard and induced risk, in connection with the agricultural practices that generally require the ignition of fires in proximity of zones rich of biomass and neighbours to inhabited zones. Fire hazard is assumed as the seasonal (average) values, I_k, of the potential linear intensity $I_k^s(t)$ [kWm^{-1}], obtained on the basis of real time meteorological data. The formal expression of risk is given by the products of three terms: the hazard I; the value or cost of the exposed elements c, and the vulnerability ζ.

Risk mitigation on a territorial system may follow two different approaches:

1. reduction of the hazard I_k, by intervention on the available fuel in cell k, i.e., forest planning toward to the diminution of the available caloric power on the considered cell (prescribed fires), or maintaining sufficient moisture fuel values by using opportune techniques able to increase the moisture value in the considered area.
2. reduction of the vulnerability v_k, achieved by means of structural or functional interventions on the territorial elements, able to decrease the vulnerability of the territory, i.e., water supply networks.

The optimization problem to be solved can now be stated as the minimization of the fire risk R_k, k=1,..,N, subject to the technical constraints present in cells k, such urban, and regional Planning, and the economical constraints given by the available budget and the costs of each resources.

As regards of the pre-operative resources management, one can observe that severe forest fires emergencies occur in presence of droughty and windy periods, whose length and spatial distribution are drawn mainly by meteorological local conditions. However, fighting-fires resources management in Mediterranean countries is characterized by local differences and heterogeneity, both in control and in technical issues. Generally speaking, Fire Brigade are sprawl in the whole (forested) territory, whereas a scarce number of airborne resources (i.e., CL 415, S64F) are concentrate in few air bases, and coordinate by a central (State) manager, whose duty is to reallocate them dynamically on the active fires. At this level, the knowledge of forecast risk dynamics $R_k(t)$, the (daily) available resources, and compatible water supplies, allow reallocating in pre-operative phase, upon a time horizon of 48-72 hours, an effective number of resources among the different air-bases. Such a problem must be formalized taking into account the objective of minimizing the weighted sum of the differences between the forecasted risk and the actual assigned resources for each cell of interest. In addition, transportation costs from a airbase to another must be taken into account, as well as the objective of penalizing the assignment of resources located at a certain base to a cell too distant from that base or to a cell incompatible with the technical characteristic of the extinguish action (distance from water supply, steepness,..).

Conclusions

An approach has been presented in this paper for the structural and operational design of a decision support system aiming at forest fire risk management in WUI. The proposed system is based on the risk assessment modelization, and heavily relies on the application of fuel moisture models and a propagation model, able to define in the selected time horizon and for the target area, the set of state variable needed for the solution of a resource allocation problem. Such a problem concerns both the planning phase, that is the design of infrastructures on the territory, and the preventive location/assignment of the available fire extinguish resource.

Several practical as well as conceptual problems remain to be investigated to assess the validity and the practical relevance of the proposed approach. Experimental evaluation with reference to a real case study is presently carried out within the Italian Civil Protection Department, which is charged to manage and dispatch the fleet of amphibious aircraft and heavy helicopters on high-risk areas or on signalled active fires.

Acknowledgement

The activities reported in the paper are presently carried out with reference to the case study relevant to the Italian Civil Protection and have been funded by the *Gruppo Nazionale per la Difesa dalle catastrofi Idrogeologiche* GNDCI, U.O. n. 3.28, Special project n. 4 *Structural and operational design of a decision support system based on a national geographical information system and aiming at forest fire risk management.*

References

Byram, G.M. 1959. Combustion of forest fuels. In Forest Fire: Control and Use. Ed. Davis, K.P. McGraw-Hill, New York, pp. 113-126.

Cheney, N.P. 1981. Fire behaviour. In 'Fire and the Australian biota'. pp. 151-175. Australian Academy of Science: Camberra

Drouet, J.C. 1974. Theorie de la propagation des feux de forets. Master Thesis Universitè d'Aix- Marseille.

Fiorucci, P., Gaetani, F., Minciardi, R., 2002. Dynamic models for preventive management and real time control of forest fires. 15th IFAC world congress in automatic control. Barcelona, Spain.

Marsden-Smedley, J.B., W.R. Catchpole 1995. Fire modelling in Tasmanian buttongrass moorlands II. Fire behaviour. International Journal of Wildland Fire 5, 215-228.