Forest Fire Management
& Fire Prevention System

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Abstract

The FOMFIS project has been funded in the framework of the EU Programme "ENVIRONMENT and CLIMATE", by DGXII. FOMFIS is a computerised system for "FOrest fire Management and FIre prevention System' based on Arc/Info, ArcView, ARC Spatial Analyst, ARC AVENUE, Visual C++ technologies) and the consolidation and standardisation of data bases management systems. FOMFIS project main objective was to integrate existing technologies under the same data environment and common user interface to producing an integrated computer system based on semi-automatic satellite image processing (fuel maps), socio-economic risk modelling and probabilistic models that would serve as a useful tool for forest fire prevention planning and management.

More precisely FOMFIS delivers a) a Data Acquisition Sub-System which provides the suitable mechanisms to transform the raw data coming from different sources into data models that will be used within the system. b) a Fuel Mapping Module that makes the transition from satellite images to a GIS raster-based coverage that illustrates the different type of fuel that the working area presents. c) Probabilistic Generation of Scenarios module that provides a scenario data structure being generated either from probabilistic analysis of historical databases (fires and meteorological ones) or / and by deterministic user driven parameter definition, d) a Socio-Economic Risk Characterisation Module that is responsible of the analysis and characterisation of the socio-economic risk in the area on study, e) an Integral Risk Analysis module that integrates the Fire Appearance Risk and the Potential Damage Risk into the Integral Risk Map, that will illustrate the final level of fire risk for every location in the area on study, f) a Probabilistic Planning module that conforms FOMFIS system nucleus, g) a Valuation Module, h) a User Interface Module that constitutes the shell for user front-end system operations.

FOMFIS project has been devised to be implemented and tested in three separate areas along Mediterranean basin. Those areas are representative of most of forest fire planning and management challenges, covering strong Atlantic influence and typical Mediterranean climate territories. The considered regions are: Galicia in Spain, Evia island in Greece, Aquitaine in France.

Several innovations included in FOMFIS could be easily transferred to on-line fire management systems; besides, the strategy could be transposed to other systems regarding natural catastrophes which demand emergency forces planning and deployment.

Integral risk estimation

Determining the potential fire destruction capacity is not an easy task. Environment variables change over time and they are barely predictable in detail. Nevertheless, it is possible to estimate general components which characterise forest fire scenarios and fire growth with reasonably accuracy.

In light of the above, pre-set wind and weather patterns could help in determining circumstances in which forest fire should develop devastating forested areas. These weather-wind combinations and their evolution over time could help to estimate the destruction potential of forest fires in advance, thus allowing managers to take preventive actions.

Integral risk maps are generated from forest fuel distribution, weather and wind patterns. Integral risk take into account the fire potential due to the fuel and the conditions together with the intrinsic value of the terrain where fire could occur. An approach to geographically characterise this integral risk has been proposed in FOMFIS system (1998), in which territory information is stored in raster layers. It is accepted the limitation to consider uniform conditions (forest fuel, slope, aspect, wind and weather) in each cell of the raster map. This allows to determine local spread conditions hence to characterise fire destruction potential.

To obtain a valid measurement of this concept, it has been proposed to consider the time t_{eq} that fire should employ in burning the area equivalent to a raster cell. For this purpose an elliptic fire spread is considered and t_{eq} corresponds to the time when the ellipse area equals the raster cell area, which is fixed by user. The same process is repeated for every cell.

This allows to consider instantaneous destruction rate expressed in surface units per time for every cell. Combined with land value per surface unit, which is estimated from economic, social and ecological components, it is possible to obtain a loss rate in monetary units per time unit. Finally, taking into account the predictions of number of fires that is expected to happen in each cell, and provided that all the fire outbreaks will propagate the same way within the same raster cell, it is possible to estimate an integral value loss rate by simply multiplying the loss rate by the number of expected fires.

These three risk indexes are calculated for every cell in the raster maps, which is synthesising the destruction potential and value loss for the whole area. The resulting maps are extremely useful to planners to understand where attention should be paid according the duality fire potential and terrain value.

Forest fuel mapping

LANDSAT and SPOT satellite images, are used as a valid, accurate, timely and cost-effective procedure to obtain forest fuel maps. It has been proposed to follow two classification approaches of vegetation units identified by image analysis.

In the purpose to obtain geographical distributions of fuel models it is required to establish a relationship table between vegetation classes and such parametrised fuel models. This is normally achieved through the utilisation of visual keys that relates USFFS models with vegetation communities. This keys have been provided by Ministeries in charge of forest fire defence in Spain and Greece.

Image classification has been aimed to identify vegetation patches, grouped by classes. A divergent approach has been proposed which establish sequential desegregation of initial coarse vegetation classes, easily distinguishable from satellite, into finer ones using other easily measurable variables, such as vegetation average height. This will lead to precise equivalence tables between models and the identified vegetation units. The convergent approach, in the other hand, starts with very fine division into a relatively large number of vegetation classes. Aggregation into coarser vegetation types will easily led to fuel models according other criteria.

Fuel load is a critical parameter in forest fuel management. It is closely associated to vegetation types (species and communities), state and age and is clearly conditioning the fire spread and fire line intensity. Nevertheless this parameter is difficult to measure form satellite observation. A very initial approach has been experimented regarding the study of correlation between vegetation indexes (such as NDVI obtained from AVHRR observations) and fuel load. Results have been somewhat discouraging due to the low correlation observed and new sources of information must be considered, such as vegetation closure and average height. Besides, any forest fuel characterisation is subject to canopy cover which is conditioning remote sensing of surface fuels.

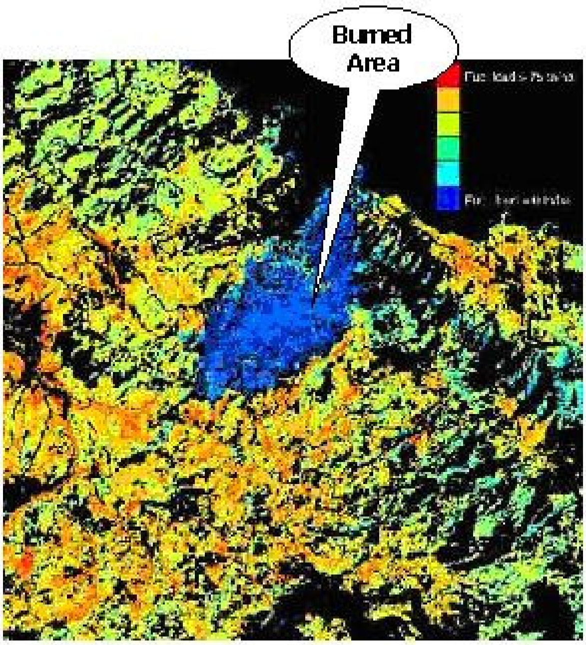

Figure 1: Fuel Loads derived for Evia Island

A multiple regression analysis of the Greek image data (Landsat TM NDVI and SPOT high-pass texture band) and the field data (active load) produced an empirical relationship between Active Load (AL) and observed vegetation index (NDVI) and texture (TX):

$$AL = 0.4 \cdot NDVI - 0.22 \cdot TX + 9.8$$

Socio-economic risk prediction

Relationship between socio-economic factors and number and typology of forest fires has proven to exist. Most of Mediterranean regions suffer this consideration and in some cases socioeconomic factors are main component in wildfire causality classification.

This has entailed the design and implementation of a Socio-Economic Risk Model (SER) which yields the expected number of fires by unit area, according the relationship between factors and forest fires, characterised through a set of expressions.

It has been proposed to substitute the traditional model of 'the most probable attributed cause' that attributes most forest fires to arsons and offenders, by a socio-economic risk model based on an objective risk situation. Appropriate analytical categories were established and risk factors identified.

This approach is hardly present in forest fires research and in the users' strategies. To develop a well founded theoretical frame, two different ways have been explored. On the one side, a microanalysis has been conducted in four forest Districts; on the other side, the insights of this qualitative work were statistically tested. As a result, five specific factors were defined for the Socio-economic Model.

In SER primary data (raw socio-economic data form different sources), variables and indicators are used. Variables are considered as qualitative elements (non-dimensional) that characterise the socio-economic setting of the forestry environment in a specific temporal or geographic unit. It has been selected a set of 156 variables that first thing, have an influence in the rise of fire risk. This set was classified in 10 groups (Forestry, Livestock, Agriculture, Land uses, Socio-demographic, etc.) and 48 subgroups according to the area of study or subjects to which they belong.

Indicators are functions that quantify the variable from the available primary data. Each variable can be quantified by more than one indicator, but among the available indicators, it has been selected those that offer greater accuracy and reliability in the representation of the variable.

Socio-economic factors are the main components or aspects which are divided in the forestry environment, and contribute to the maximum causal explanation in the intensity and variation of fire risk. SER has defined and worked with 5 factors, namely :

- Forestry profitability (production and productivity in the forestry environment),
- demographic pressure (degree of human presence and evolution in forest areas),
- social tension (social strain level),
- forestry culture (level of forestry culture and public opinion), and
- organisational logic (prevention and fight model).

These 5 factors are supposed to be sufficient to explain the increase or decrease of fire risk. Three separate models have been designed, according the nature and geographical scope of the analysis.

Galician Spatial Model

It consists of a macro-model applicable to geographic units of middle extension, the municipalities or groupings of parishes with an average area of about 100 square km. The model has been obtained by means of spatial regression analysis of average FF data and socio-economic variables of the period 1991 – 1996. The result of its application is an estimate of the number of fires expected during a year per 100 km^2 of forest area for climatic conditions similar to those which average the period 1991 – 1996.

The equation works with seven variables for a start with a high degree of independence among them. All of them have a positive effect on the rise of the dependent variable. Then the above-mentioned variables are enumerated together with the impact coefficients (Standardised beta coefficients) that assess the specific weight of each of them: Agrarian Holdings

Density (+0.41); Total Population Density (+0.29); Agricultural Land-Forest Interface (+0.21); Proportion of brushland (+0.18); Proportion of unemployed male population (+0.15); Disseminated Housing Density (+0.15); Sheep and goats Density (+0.14). The formula has been obtained by regression of 311 municipality with a 0.54 Adjusted R^2 and 60% Maximum Relative Error in 70% of the cases.

Greek Spatial Model

The model has been obtained by means of spatial regression analysis of average forest fires data and socio-economic variables of the period 1983 – 1993. The dependent variable is the number of fires expected during a year per 100 km^2 of total area for climatic conditions similar to those which average the period 1983 – 1993. The independent variables are two: The Municipality Density and A3GO (Complex variable related to Livestock). The Municipality Density is highly connected with the ratio of urban area and it is a clear essential component in the determination of the risk. A3GO is a complex variable. It combines two important factors related to goats grazing pressure: On the one side the Goats Density and on the other side the average grazing area per goat holding. The formula has been obtained by means of regression of 51 cases with a 0,73 Adjusted R^2, and 28% Maximum Relative Error in 70% of the cases.

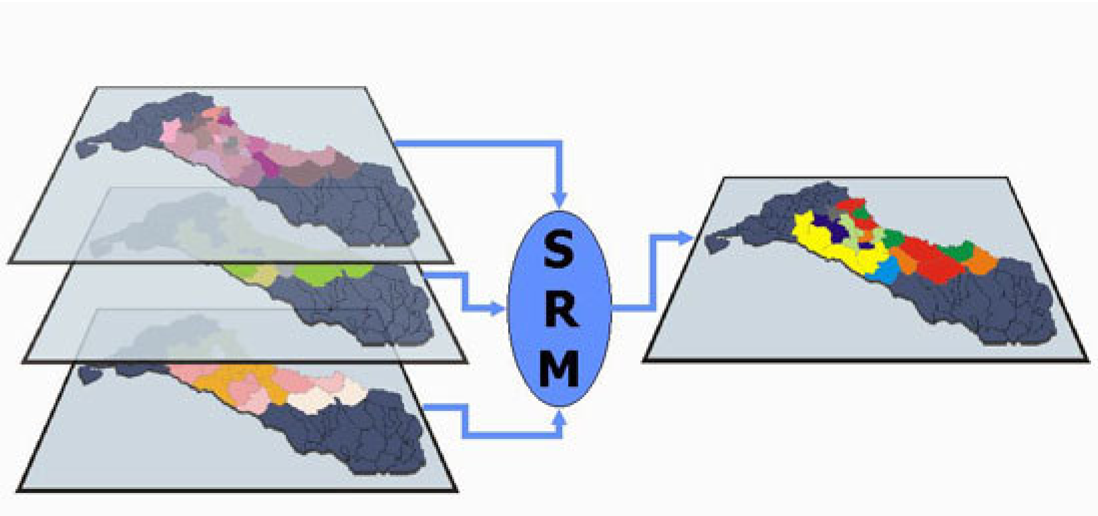

Figure 2: Sosioeconomic Module: Estimation of Sosioeconomic Risk

Galician Temporal Model

It is a macro-model applicable to geographic units of large extension such as the Provinces. The formula has been obtained by means of temporal regression analysis of forest fires data and socio-economic variables determined per year for the whole of Galicia. 29 were the number of years used for the regression from 1968 to 1996. It is a model of temporal application that allows to explain the variation of risk from year to year.

Besides to the models listed, two predictive, micro scale models have been developed for the Comarca of Noia (Galicia) and Dasarheio of Limni (Evia) which give number of fires per unit area (100 km^2). This micro-models give more accurate results than macro-models mentioned above.

Fire defence service planning, efficiency-oriented

Forest fire defence efficiency could be conceptually simplified as the minimisation of time involved in the operations, such as fire detection, communication to base, forces preparation and start-up, air and ground transport, deployment of resources in the fire area and fire extinction and control. To pre-determine the efficiency in such simple terms it has been proposed to apply spatial analysis techniques to the existing resources in a region. Planners are allowed to play with different distribution of bases, water points, lookouts and roads and see the effect in terms of efficiency of their new locations.

The calculation of access time of ground vehicles has been performed traditionally by network analysis GIS tools. It has been proposed to use spatial analysis instead, using raster maps vs. vector coverages. Thus, roads are converted to raster cells into which a transport-resistance value is stored, depending on the type and state of road and terrain slope. This is interpreted as time values, those invested by vehicles in crossing each cell. Cross-country access is considered also, and for this type of displacements type of vegetation and slope are considered in the calculation.

From this ground 'Impedance Map' it is possible to derive accumulated time access map which is calculated by iterative automata following the minimum-time path. The resulting map stores the time invested in travelling from a given point to every cell. Thus, ground coverage, that is the percentage of cells which access time is equal or less than a prescribed threshold time. Road network improvement and forest accessibility works have a direct influence in this percentage.

Aerial coverage is estimated by directly considering distances to airbases and average speed of aircrafts. The resulting map is combined with ground access to estimate real coverage of fire fighting resources. Together with estimation of access time to the fire area, these mentioned maps are used to calculate efficiency of fire vehicles in their water re-charging cycles to the nearest water point.

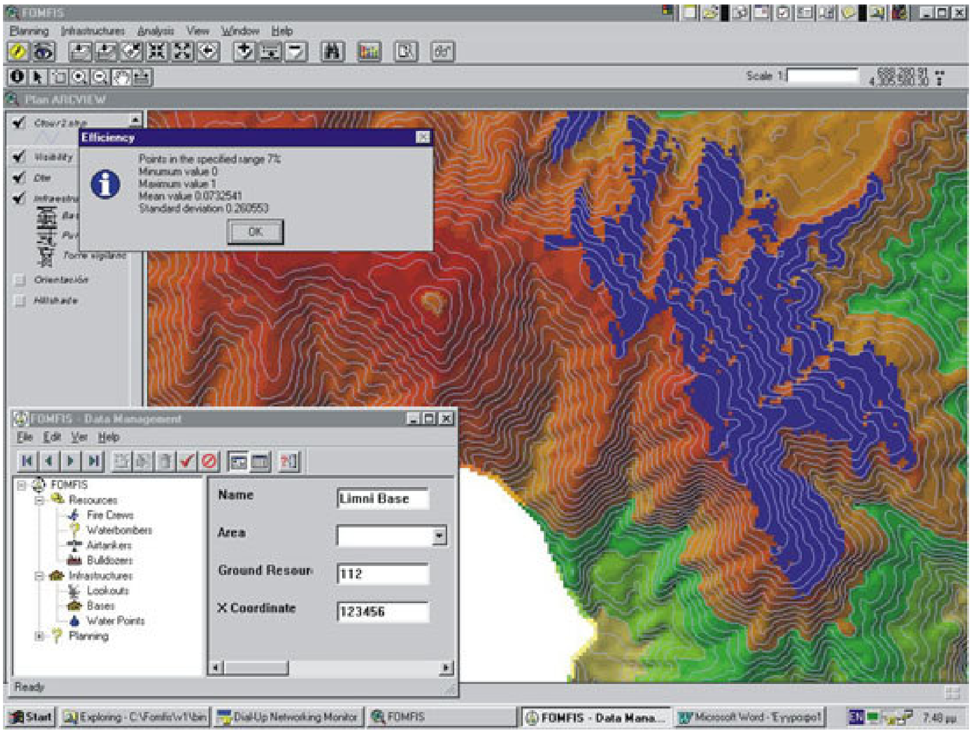

Figure 3: Visibility Calculation from the Lookouts

Lookouts efficiency, understood as the percentage of points in the region that is covered by vigilance network, depends mainly on their position in the terrain. Thus, it has been proposed to establish a relationship between vigilance coverage degree and fire detection time. To achieve this an analysis of viewsheds has been completed from the Digital Elevation Model of the studied regions.

Fire fighting efficiency calculation has shown to be more complex. It involves the knowledge of fire-fighters and vehicles productivity for every fuel model, under circumstances that vary largely. Cross-country ground accessibility is conditioned by vegetation coverage and slope. Fire characteristics reduce or even limit fire fighting in direct attack, and the construction of fire line is mainly restricted by vegetation and slope. Air attack efficiency could be diminished also due to many factors, such as wind speed, smoke density, topography or available light. All these considerations are taken into consideration in the simulation of fire fighting operations, reduced to a set of operations: direct attack over flames, indirect attack and aircraft water discharges. All the calculations are based on real data and observations which give average values of productivity.

Proposed planning of infrastructures works, locations, improvement and forces depletion in a region has a cost. To optimise the assigned budget, it has been proposed to do planning configuration according the predicted risks, understood in terms that have been explained previously. This ability to combine risk forecasting, efficiency and costs is a real added value for a decision taking aid system.

Fire theatre simulation

Once obtained the fire scenarios evolution and fire defence resources and infrastructures planning, it has been proposed to simulate their interaction over time and to estimate costs of operations and losses due to wildfire destruction. Simulations count on a very efficient forest fire spread engine which is calculating fire propagation and fire characteristics for every cell. Flame length, heat per unit area and fireline intensity are also estimated and used to dimension the required forces to achieve a successful containment and extinction. Nevertheless, only surface fires are modelled.

It has been proposed to compute an indicator of fire importance for every fire outbreak in the region. This value should evolve over time as fire perimeter changes in size, location and intensity. Instantly fire importance should be used to adjust fire fighting resources and to allow efficient dispatching. Other criteria is considered such as administrative dependence or fire fighting units availability.

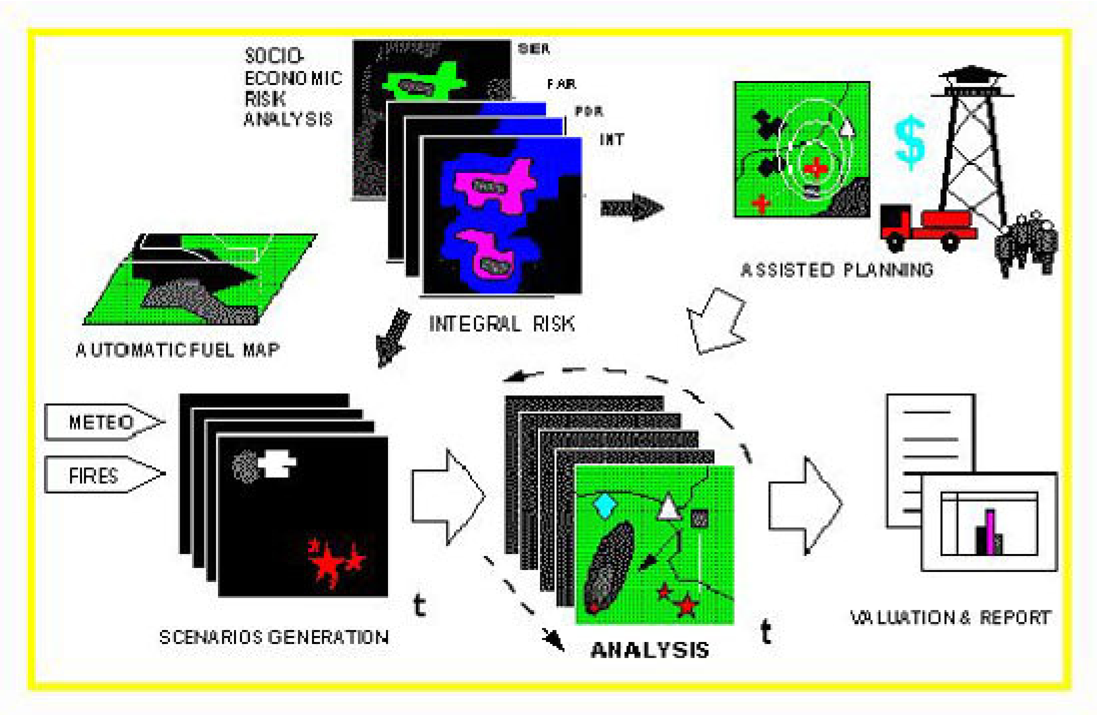

Figure 4: Overall System Architecture

Fire fighting units are dimensioned and assigned to fires depending on importance and immediate action criteria. Frequently there is less fighting power assigned to fires than required, due to lack of fighting units availability or excess of demand, such as in those peak-days in Galicia. In these cases fire containment could not be 100% effective thus allowing fire to escape. The system will then simulate such fire until it has gained enough importance to absorve fire fighting resources in the region that control and extinguish it.

Previous dispatching computer models [Xanthopoulos] take into consideration fire perimeter growth and estimate the required fighting forces to achieve enough extinction rate. To improve this approach it has been proposed to consider four different classes of fire perimeter according the fire line intensity and its variation over time. For every of those intensity classes different growth rates are considered and, consequently, the total required extinction power is weighed depending on the demands for every class.

Fighting actions, such as direct attack, water discharges and indirect attack, have variable effect over such intensity classes. Conversely, as fire fighting actions are restricted according the fire intensity, this new approach contemplates fire fighting actions that reduces intensity allowing other forces to complete fire extinction. Thus, this approach considers coupled productivity of different fighting units, such as aerial discharges, that reduce fire line intensity, coupled with ground attack which is acting over such reduced flames down to complete extinction.

Evaluation and reporting

The system simulates fire theatre during the simulation time period. This time interval varies from one day to several months. As fire scenario components, such as weather and wind, are obtained from probabilistic calculations they could differ from real world in a single simulation. Thus, it has been proposed to run several times the same simulation but adding slight, stochastic variations every time. The system will compute, in the end, average tendencies of fire theatre evolution to give just orders of magnitude, instead of deterministic predictions.

Results of simulation are presented in form of tables and graphics. They include weather and wind pattern evolution, fire outbreaks distribution, fire growth average values such as size, fire line intensities, fire importance etc; together with such values several reports are obtained regarding the resources usage, dispatching and efficiency.

Simulations render also results in terms of monetary values. The cost of fire defence operations carried out during the simulation period and the infrastructures maintenance cost are computed also and then compared with monetary losses estimation due to fire destruction.

The final evaluation allow planners to identify which strategies could have deeper impact in the final results, comparing costs, efficiencies and losses.

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