An operational tool for fire management and fire prevention planning for public administration (Tuscany Region - Italy)

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Abstract

To better organize the forest fire fighting activities of prevention and suppression the Tuscany Region Administration has decided to use a complex model for the evaluation of the risk of the territory. This model has been named Final Risk Index (FRI). It is the final result of the combination of different intermediate indeces, the principal ones of whom are: the Global Risk Index (GRI) and the l'Operational Difficulty Index in Firefighting (ODIF). In the beginning these two indices were developed separately by the IBIMET – CNR and DISTAF of the University of Florence, after they were integrated to generate an efficient tool for the planning and management of all the forest fire activities, in fact the model is now able to provide information to different scale of time and territory. In terms of time it can give information from the daily risk or to the seasonal risk while in area terms it can visualize pixel from 10x10m to 400x400m, these data can be aggregated to laid out a map of risk for single pixel , for the whole territory of a municipality or for homogeneous areas, ecc.

The GRI gives an indication of the risk of a territory developing a "Static hazard and a Dynamic hazard". The first one is the evaluation of the vegetation, the morphology, the aspect and road network., while the second one is the elaboration of the meteorological data. These values are then integrated with the evaluation of the social component, that is given by the historical statistic analysis of the ignition points. The mathematical elaboration of these data gives an estimation of the probability of ignition of a forest fire in an area. Anyway this index doesn't allow to estimate the suppression difficulties of the fire

ODIF gives these information. The index analysed several factors affecting the extinction activities of the fire squads and the aerial means. The road network, the water points distribution, the types of engines and squads are the elements that are evaluated by the model. The final result is an estimation of the efficiency and effectiveness of the fire fighting organization in a determined area.

Anyway FRI is able to provide other information useful for a complete planning of the forest fire fighting activity. FRI is still in a testing phase, because not all the component has been enough validated. GRI has been tested for to a regional level only for the "static hazard and not for the Dynamic hazard, while ODIF has been validated to the municipality level and is now on the provincial level. The final development is due for the end of 2008.

Introduction

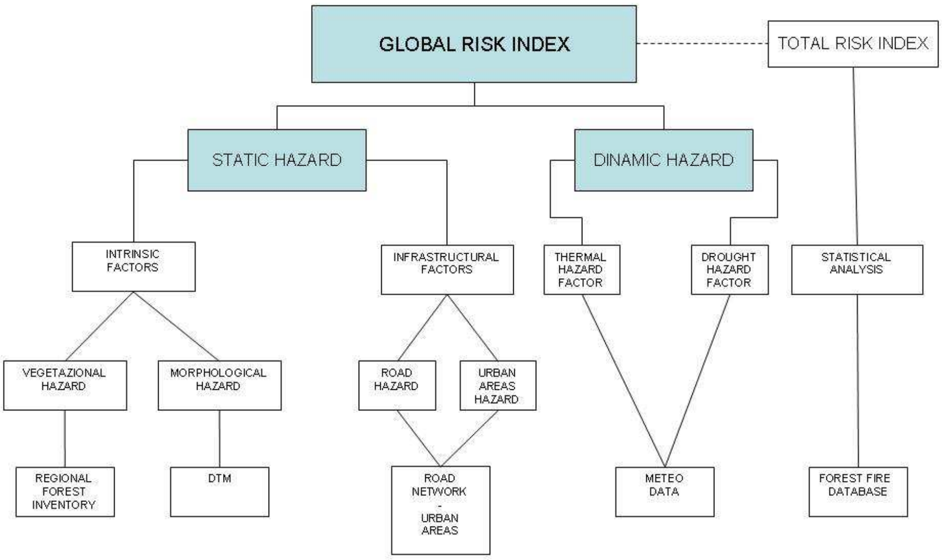
The law in Italy give the duty to the Regional Administrations of managing the forest fire fighting activities. The law binds to develop some operative plans which has to give indication on the way how prevention and suppression are organized, besides the plans must be integrated with the indices for fire risk, the list of the means (ground and aerial), firebreaks, look out towers, radio network, etc. Al these information are collected in different database often they are not connected in a tool able to give information in real time on the type of fire that is spreading, on the damage that can do and on the best way to put out.

With this work we want to develop an operative tool that, starting from the database used to elaborate the forest fire fighting plans, it was able to show an index easy to consult for the personnel employed in the operative rooms but also for the ones whose job is to planning the prevention activities.

This index called FRI (Final Risk Index) is done by the integration of other two indices that will be described in this article: GRI (Global Risk Index) and l'ODIF Operational Difficulty Index in Firefighting). The final version of FRI will be ready for the end of 2008. So far the GRI has been validated by the Tuscany Region for the "static hazard" while is still on experimental phase the dynamic hazard in which are elaborated the meteorological data in real time. ODIF has been tested at municipality level, while is still on the validation at provincial level. The most difficulties find in the elaboration of the two indices are due to the fact that the territory of Tuscany is morphologically various, in altitude we go from the sea level to 2000m high at the top of the Apennine mountain chain, this variation influenced the forest types, the weather, the winds directions and on the behavior and types of fires. Tuscany compare with other Italian region has forest fires all year round differently from the center- south regions where the fires are in summer and the north regions where the fires are in winter. The months with the most number of ignitions are July, August and March. All these elements needs to be analysed very carefully especially when they must be introduced into the model

The structure of the Global Risk Index

The ignition and spread of a forest fire are strictly connected to many parameters which needs to be analysed simultaneously to evaluate the risk of a territory. This model has been developed taking into account the monitored data by the Tuscany Region, anyway his structure is realized in a way that could be easily integrated with other information if they will be at disposal; for example so far we haven't any data on the types of fuels (dead/alive, dimension, vertical and horizontal distribution, weight/hectares) or about the relative moisture and in part on the direction and intensity of the winds. The model has been developed following in a pyramidal scheme, that is typical even in other index developed to evaluate the fire behaviour and risk of an area (the Canadian Fire Weather Index for example), so the final result is the amount of the different intermediate indexes, each of them with a different weight. We can affirm that the GRI is the integration of two values: the first is the Static Hazard the second the Dynamic hazard. In the schema 1 is shown how this values have been built and elaborated.



The input data of the model are at the bottom of the diagram and they are:

- DTM (digital terrain model) the data has been elaborated at 90m scale
- The Regional Forest Inventory gives an indication of the principle tree species on a grid of 400m side;
- The Road Network and the Urban Areas are used to evaluate the social component in relationship with the points of ignition;
- The Meteorological parameters are taken from the national or the regional meteorological network ;
- The Forest Fire Database gives the geographical coordinates of the igniton points, the burned surface, the type of forest, the duration, the ground and aereal means, the number of personnell, etc.

Static hazard

In the static hazard all the factors that don't change in time or space or that change very slowly are examinated. To built this index there are two components that have been called: Intinsic Factor and Infrastructural Factor.

The Intrinsic Factor is obtained starting from the analysis of the morphological components of a territory (Morphologic Hazard) such as the Topography (Slope and Aspect), the land use, the vegetation cover (Vegetational Hazard). Is well kwon that aspect is one of the most important factors that influence on fire propagation and on his behaviour while aspect has an influence on the water content of vegetation, on the temperature and on solar radiation

On the basis of the some information collected in test areas, and after a validation with he use of the forest fire database, some qualitative classification classes of the risk for the calculation of the Morphological Hazard has been defined *(Table1)*

Table 1—Morphological classes of risk.

MORPHOLOGICAL HAZARD LEVEL	Slope Classes	Aspect classes
VERY HIGH	>45%	S-SW
HIGH	25-45%	W
MODERATE	15-25%	SE
LOW	5-15%	E
VERY LOW	<5%	Flat surface, N-NW, N-NE

Slope and Aspect have been weight in a different way adding a multiplicative factor. The definition of the weight has been done taking into account the historical analysis of the fires, at the end the opinion of the operative personnel of the Tuscany Fire Fighting organization has been asked to see if our results could be comparable with the "experience on the field".

The final value is the results of the following formula

Morphological hazard = (Slope * 0.6) + (Aspect *0.4)

The second element that is necessary for the Intrinsic factor determination is the types of vegetation analysis. To have a less complex model has been studied the physiological phases of vegetation in the different season (absence/presence of the leaves, quiescence/metabolic activity status, etc.). The short-term evolutions of the vegetation status will be considered by weighting and taking into account the meteorological factors in the elaboration of the dynamic hazard.

Different types of land cover are defined by re-classifying the Forestry Regional Inventory in according with CLC classes (Corine Land Cover - European Commission,1994). The main groups of vegetation types introduced in the model are: Anthropical areas, Agricultural areas, Forest areas, and Damp zones. Each class is divided in sub-classes to point out the different stands features.

To simulate the seasonal evolution of vegetation cover, a different set of hazard classes has been defined for each season and for each vegetation class.

To calculate the Intrinsic factor, the influence of morphology and vegetation haven't the same weight, this consideration is due to the experience of the operators of Regional fire fighting organization.

Intrinsic factors = (vegetation hazard * 0.6) + (morphological hazard * 0.4)

The Infrastructural factor is obtained considering urban areas (Urban Areas Hazard) and road network (Road Hazard); in particular it involves road network density per square kilometre and the distance from the urban areas. These two components are relevant because in Tuscany, the majority of fires (more than 98%) take origin from human activities (incidents or criminal actions) and statistically the most number of ignition points are close to urban areas or along the roads (Tuscany Region,2004).

For the elaboration of the "road hazard" a demographic function of a GIS program, called Density, is used; so we have a different hazard level for each pixel of the road shape. After these different values are divided in five classes from: "very-high" to "very low" (Natural Breaks Jenkins -Jenks G.F. et al. 1971). The urban areas are defined and classified using the layer created by Tuscany Region. The hazard levels have been assigned on the basis of distance buffer from urban boundaries, using the same classification method applied to the road network.

Infrastructural factors = (road hazard * 0.6) + (urban hazard * 0.4)

Even in that case a corrective value has been applied because the analysis of the ignition points shows an higher frequency of fire along the roads than the urban areas

Finally the Static Hazard is computed in raster format as a sum of the previous factors:

Static Hazard = (Intrinsic Factors * 0.6) + (Infrastructural Factors * 0.4)

The multiplicative value is higher for intrinsic factor (0.6) because the morphological factors and the vegetation are strictly related to the fire risk ignition and its spread.

Dynamic hazard

The dynamic hazard takes into account parameters that show short-term variations. The main factors are climatic and microclimatic conditions and vegetation status (especially water content). because they influenced the ignition and spread of a forest fire. The estimation of vegetation water content is difficult data to obtain but it is closely related to local meteorological conditions, so this element is valued by meteorological variables (Viegas 2000).

The meteorological parameters affecting the probability of ignition considered in the model are:

- Temperature: high temperatures affect the evapotranspiration rate and increase the drying speed of the soil moisture.
- Rainfall: the amount of rainfall affects the water balance of forest and agricultural ecosystems. The soil water content increase after a rainfall and decrease by evapotranspiration. Therefore, the vegetation, which represents the availability of fuel during the ignition, increases or decreases its humidity content in relation to the soil water content and atmospheric humidity.
- The number of days without rain: this factor is introduced in the model to classify, in a speed way, the fall in water levels in the ecosystem. Drought is an extremely important indicator for danger of wildfire occurrence. Statistically very intense fires can occur also on the 2nd or 3rd days after precipitation, because fuels reach a level of dryness and require significant humidity elevation to return to the moisture extinction point.
- Rainfall threshold: is the mm of precipitation during a period. In the model different seasonal thresholds are defined to represent the quantity of water to reach the moisture extinction point.
- Global radiation: where direct measurement of solar radiation isn't available, an easy system to calculate the global radiation is to make an estimatation by using an internal function of GIS system (Solar analyst).

Meteorological factors are combined by the model to elaborate two different meteorological-related hazards: Thermal Hazard Factor (THF), computed by means of the maximum air temperature analysis and Drought Hazard Factor (DHF), which takes into account the net rain and the number of days without rain.

To determine the THF, the distribution of the wildfires in relation to the maximum temperature values has been analysed. The thresholds to classify temperature hazard have also been defined.

This analysis is performed on the daily data and produce a seasonal index. Each daily temperature value is classified on the basis of the threshold value, according to the following rules :

°C of T max	Value
Tmax <1	0
Tmax >1 and Tmax<15	range between 0.1 and 1
Tmax >15 and Tmax<25	range between 1.1 and 2
Tmax >25 and Tmax<28	range between 2.1 and 3
Tmax >28	4

The DHF is computed in two phases: rain net definition and rainy days definition.

The THF and DHF are at last interpolated with the following formula to define the Dynamic Hazard:

Dynamic Hazard = ((THF + DHF) / 2)

Global index and Statistic information

The static and dynamic hazard are mathematically combined in the model to obtain the Global Risk Index (GRI).

Global Risk Index = (Static Hazard * 0.6) + (Dynamic Hazard * 0.4)

The multiplicative factor is higher for static hazard (0.6) because its component (morphological and vegetation) provide a real image of the areas that are stable for a long period. On the other hand the component of dynamic hazard are the results of the elaboration from measured data including some possible errors. The GRI of a territory can be visualised as a raster format layer which can be superimposed on a topographic regional map

As a next step, the global index may be integrated with the statistic information elaborated from the AIB. The number of fires per year since 1984 to 2002 has been calculated for each Tuscany municipality. Then all this data has been normalized to redistribute all the values in five hazard classes, starting from the highest number of events.

Finally we obtain the TRI (Total Risk Index) in raster format which can be also superimposed on a topographic map.

The TRI can be visualised at two different levels: a raster layer that expres the riskfor each pixel for the whole territory of a Municipality.

The structure of the Operational Difficulty Index in Fire Fighting - ODIF

The structure of the ODIF model has been developed taking into consideration the suppression methods and tactics used in Tuscany. On this basis, the main variables influencing firefighting efficiency and effectiveness have been determined.

The first variables concern the initial attack efficiency, determined by means of the distances needed to be covered to reach the different forest areas:

- **Vehicles access distance (VAD):** distance between the closest road to the potential burning area and the closest firefighting base.
- An higher level of difficulty will be applied in the model at the increase of the distance *(Table 2).*
- **Helicopter access distance (EAD):** distance between the closest helicopter base and the potential burning area. As before, to a greater distance corresponds an higher elapsed time to reach the area and starting the initial attack, so the level of difficulty applied in the model is higher *(Table 2).*

Other variables describe operational difficulties:

- **Firefighters Operational Difficulty (FOD)**: the effectiveness of firefighter crews depends both on the distance to reach the fire-line from the closest road and on the ground slope (Bovio, 1993). To an higher value of the distance and the ground slope corresponds a greater operational difficulty level applied in the model *(Table 2).* For the determination of the levels, travel times were analysed. We assumed that firefighters with tools can walk on flat terrain at 4 km/h and cover a difference in height of 400 m/h on steep terrain (Hippoliti, 1976, 2003). Watercourses between road and fire-line imply the highest FOD.
- **Vehicle supply distance (VSD)** = distance from the road, closest to the potential burning area, and the closest waterpoint. To determine the level of difficulty we assumed that the distance should not exceed 4 km, as confirmed by the Tuscany Regional Operational Firefighting Plan (Tuscany Region, 2004).
- **Helicopter supply distance (ESD)** = distance from a potential burning area and the closest waterpoint for helicopters. We assumed that the maximum distance should not exceed 6 km to have the minimum operational effectiveness, and 2 km to reach the maximum effectiveness as confirmed by Hunt (1986), and by the Tuscany Regional Operational Firefighting Plan (Tuscany Region, 2004).

The input data to run the model are a digital terrain model (10 m) and the infrastructures shapes. The shapes include all the surveyed data, i.e. the location of : public and forest road networks; water supply points (classified in: ground vehicles water sources and helitankers water sources); helitanker bases; and firefighter centers.

All the variables are mathematically combined in the model to obtain:

- ***Ground Operational Difficulty Index (GODI***) calculated as:

GODI = (VAD * 0.4) + (VSD * 0.3) + (FOD * 0.3)

Helicopters Operational Difficulty Index (HODI) calculated as:

HODI = (HAD * 0.4) + (HSD * 0.6)

Finally GODI and HODI are combined to obtain the ODIF:

ODIF = (GODI * 0.7)+ (HODI * 0.3)

The multiplicative factors introduced to weight the variables are determined on the basis of the experience of Tuscany fire managers and of the results of forest fire and helitanker database analysis.

The output are maps in raster format where each pixel shows the value of ODIF.

Table 2 - Classes and difficult level for each variable used to calculate the ODIF

Variable	Class	Difficult level	Value
Vehicle Access Distance (VAD)	>10.0 km	VERY HIGH	4
	>7.5-10.0 km	HIGH	3
	>5.0-7.5 km	MODERATE	2
	>2.5-5.0 km	LOW	1
	≤2.5 km	VERY LOW	0
Helicopter Access Distance (HAD)	>40 km	VERY HIGH	4
	>30-40 km	HIGH	3
	>20-30 km	MODERATE	2
	>10-20 km	LOW	1
	≤10 km	VERY LOW	0
Fire-Fighting Operational Difficulty (FOD)	>10 min	VERY HIGH	4
	>7.5-10 min	HIGH	3
	>5-7.5 min	MODERATE	2
	>2.5-5 min	LOW	1
	≤2.5 min	VERY LOW	0
Vehicle supply distance (VSD)	>4 km	VERY HIGH	4
	>3-4 km	HIGH	3
	>2-3 km	MODERATE	2
	>1-2 km	LOW	1
	≤1 km	VERY LOW	0
Helicopter supply distance (HSD)	>6.0 km	VERY HIGH	4
	>4.5-6.0 km	HIGH	3
	>3.0-4.5 km	MODERATE	2
	>1.5-3.0 km	LOW	1
	≤1.5 km	VERY LOW	0
ODIF		VERY HIGH	4
		HIGH	3
		MODERATE	2
		LOW	1
		VERY LOW	0

GRI and ODIF combination

GRI and ODIF have been implemented separately although they are strictly correlated, as they use the same layers of road network and similar concepts to classify the results. The global risk index and the operational difficulty index are two useful tools. When combined, their efficiency is higher, producing a power instrument for planning the forest fire emergency.

In this experimental phase, GRI and ODIF have been joined in the FRI Final Risk Index, by analysing all possible combinations (pixel by pixel) of the two variables *(Table 3*) and result in the following classes.

- Class 0: Very low final risk. No fire planning or prevention activity is needed.
- Class 1: Low final risk. The standard operational procedures and prevention activities are needed.
- Class 2: Moderate final risk. Some specific procedures and prevention activities may be organized, like patrolling activity during the most dangerous times of the day.
- Class 3: High final risk. If a few areas are in this class, only some specific prevention procedures and infrastructure maintenance may be applied. If large areas are in this class, a medium-long term infrastructure planning has to be applied (forest road planning and maintenance, waterpoint construction, helitanker bases or firefighter centres reallocation analysis).
- Class 4: Very high final risk. If a few areas are in this class, only some specific prevention procedures and infrastructure maintenance may be applied. If large areas are in this class, both specific prevention procedures and short term infrastructure planning have to be applied

Table 3 Combinatrion matrix of GRI and ODIF

		ODIF value				
		0	**1**	**2**	**3**	**4**
GRI value	**0**	0	0	0	0	1
	1	0	0	0	1	1
	2	1	1	2	2	3
	3	1	2	2	3	4
	4	1	2	3	4	4

For each GRI and ODIF combination with the same value, some planning or prevention activity may be suggested on the basis of the Regional experience and organization, and of the Regional Operational Fire fighting Plan of Tuscany Region 2004-2006:

Conclusions

At the Regional level, the results obtained with the Global Risk Index in summer and winter reflect the level of warning recorded by the Regional fire fighting organization. In fact, most of the Region has a "very high" or "high" global risk in summer *(Table 4).* For the summer season, this risk distribution is strictly related to the meteorological conditions, e.g. high temperature and low precipitation. Even in Winter, with low temperature and good rainfall, the percentage of areas classified "very high" by the system is, however, 15%. This value is mainly due to some areas of the Apennine mountains in which the meteorological conditions and aspect increase the risk level during the winter.

Table 3 Global risk percentage for hazard class (from very high to very low) in summer and winter

Regional Level	Winter	Summer
VERY HIGH	15%	37%
HIGH	11%	16%
MODERATE	21%	27%
LOW	35%	15%
VERY LOW	18%	5%

To plan forest fire fighting, GRI may be integrated by ODIF in order to achieve the reduction of operational difficulties. So far the application of the ODIF has been done in some Municipality all around Tuscany and it is still in progress at provincial level.

The results highlight the potential of the operational indices, even if the methodology should be applied to larger areas with diverse characteristics in order to assess its feasibility in forest fire planning and to determine eventual methodological changes.

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