FORFAIT

Knowledge Base – General overview of forest fires
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General overview of forest fires

The main goal of defence services against forest fires (generally known as Forest Fire Services) is to minimise their impact on the population, the properties and the ecosystems at risk. Forest fires are a specific type of fires for which behaviour-governing conditions are not uniform in time and space, and develop over an open scenario. Besides, forest fires release high amount of energy (usually 3 to 6 MW/m, up to several dozens of MW/m) and in some cases span over large areas. Smoke production is a main effect which directly affects people in the surroundings, fire fighters, animals and diminishes air quality locally (and in severe cases regionally), which effect includes production of pollutants (CO, C02, NOx, 03), particles concentration rise and decrease of visibility.

Under adverse conditions, forest fires develop rapidly from light forest fuels (cured grass, litter, thin slash) in the surface to heavy ones (dense shrubs, trees plantations, young forests, timber slash), and finally to trees canopy (older forests). The factors which affect the initiation and buildup of an initial fire are mainly the type (active fuel load, structure, flammability) and status (moisture content) of forest fuel, the wind and the topography. Topography and fuel load could be considered as short-term time-static factors, although they vary in space; but weather (hence the amount of water in the forest fuel) and wind-co s change noticeably in time; hence, fire behaviour varies space and time.

The issues mentioned above point to the need of a synthetic characterisation of forest fuels and their distribution, the topography and the evaluation of weather and wind conditions spatially and their changes over time. All the mentioned information comprises the intrinsic values of fire danger, and explain the fire potential in a region.

On the other hand, fire initiation causes vary enormously according different regions, but can be synthesised into the following main groups:

- Natural causes, such as lightning
- Causes due to human activity:
  - Voluntary causes, due to particular interests or arson
  - Accidental causes, such as railroads, disposal sites, field works or urban areas

Although in some regions of Europe lightning is cause of up to 15% of forest fires, in most of cases this is a small fraction of about 2% to 8%. The rest is due to human activity, and frequently (75% to 90%) because of accident. Most of accidental fires occur along or in the vicinity of human structures (roads, railroads, buildings, urbanised areas, recreational infrastructure, disposal sites etc.), which position in space is known.

Other, such as those due to filed agricultural or selvicultural works which make use of fires, cannot pinpointed precisely in space (diffuse distribution), but in turn, and in most cases, the time of application is known. Finally, lightning-originated fires cannot be predicted in location nor in time but, thanks to specific radar detection devices, lightning-prone areas can be mapped.

All this information is usually gathered in fire danger indexes (for intrinsic danger values) and fire risk indexes (including also causal factors), which algorithms are implemented in Geographical Information Systems (GIS) and results are presented in form of maps (generally known as fire danger map and fire risk map).

Cost-effective fire response strategy includes three elements: a centralised command and control organisation, rapid detection, and aggressive initial attack. Without all of these elements some fires are destined to escape initial attack and, particularly in the wildland-urban interface, that can often result in significant loss of valuable resources and possibly lives. The most effective and versatile initial attack resource in these circumstances is undoubtedly fire fighting aircraft, fixed-wing and rotary-wing. Properly deployed, managed, and integrated with ground forces, attack aircraft can reach interface fires quickly, hitting them hard and frequently to contain them.

Forest fire management chain

Although there exist a different scheme of forest fire management for every region in Europe, it is easy to identify a set of common points which are present in all countries involved. The scheme presented must be understood as a general one which, saving the details which will be analysed later, could be assumed to be roughly the same for all fire services. It has been identified five different phases which embraces all possible situations in a typical sequence of the forest fire management chain:

1- Preventive activities and training, long-term planning
- Works on forest fuel
- Works on forest fire defence infrastructure
- Citizen education and sensibilisation
- Personnel training

2- Previous to fire events, short term and daily planning
- Meteorological data capture, forecast and analysis of weather and wind
- Estimation of fuel moisture and ignition probability
- Identification of potential sources of fires
- Estimation of fire danger and fire risk
- Pre-alert deployment of fire forces according danger/risk level

3- In case of fire event, initial attack
- Surveillance and detection
- Estimation of position of fire outbreaks and access routes
- Estimation of fire severity
- Analysis of immediate danger and values at risk
- Dispatching of fire fighting resources
- Transportation of forces
- Deployment of forces and initial attack
- Aerial support (water bombing and transportation)
- Mobilisation and co-ordination of heavy machinery
- Tracking and management of fire fighting forces
- On-site assessment on fire attack

4- In case of severe or/and large fires
- Planning of emergency, deployment of co-ordination points
- Continuous information service on evolution of meteorological conditions d fire
- Mobilisation and organisation of extended attack forces
- Mobilisation of complementary forces
- Mobilisation and co-ordination of Civil Protection forces
- Mass media communication service
- Logistics
- Health care and medical services

5- After the fire
- Control of fire extinguished perimeter and mop-up
- Measurement of final perimeter area and shape
- Estimation of losses and costs
- Investigation of causes

Deployment of forces and initial attack

Once the fire has started, the initial attack is the action taken to halt the -spread, or potential spread, of a fire by the first fire fighting force to arrive at the fire.

Ground Crews. The land units are typically composed of eight to 15 completely equipped and trained professional firefighters who operate manual tools, fire equipment and mechanised equipment (portable chain saws and motor pumps) with high safety standards. They are transported in light and medium vehicles (4x4 vans, minibuses, buses and trucks) and tanker trucks, and apply Class A suppressant foam. These vehicles make it possible to arrive at fire locations quickly.

Helicrews, smoke-jumpers, fire-tackers. The same considerations as in case of ground crews, just that the access to the fire area is done from and plane or helicopter by *jumping or descending*.

Fire trucks, engines and hoses. Fire trucks are vehicles prepare to endure extreme situations, observe strict safety rules and move through mountainous, tough terrain. Fire trucks are used mainly in direct attack and are equipped with pumps driven by the truck engine or autonomous motor. The specifications allow to fire fighting in irregular terrain, while the vehicle is stopped or moves at low speed or to supply with water in sections with light means. Size and types of trucks vary a lot, but they can be classified according the number of tons of water they can carry. In such sense, light trucks have loads of 1.6 to 2 tons of water, medium size load 2.5 to 4 tons and large ones more than 4 tons of water.

Tankers. Tankers are present in the fire area, carrying large amount of water, typically from 10 to 20 tons, and giving support to ground crews and fire trucks when water is scarce. In some extreme cases, ground tankers also serve to re-fill fighting helicopter water tanks.

Fire extinction operations

Direct attack regards any treatment of burning fuel such as wetting, smothering, chemical quenching, or separation of burning fuel from the unburned to reduce or stop fire advance. It is applied with ground means only or, more usual, in combination with aerial means. The head attack is applied in the lead edge of the fire perimeter to stop fire advance. Massive involvement of means in the head of the fire, then the fighting units are divided into units and the extinction works continue along the flanks. The flank attack are carried out from a point in the perimeter which is less active, advancing towards the front of the fire to contain it. In many cases the forces break through the flank of fire perimeter, penetrating inside the burned area, to advance in the burned area towards the head of the fire, using roads or ways when it is possible. In practice, one limiting factor of this firefighting procedure is the radiation which forces the firefighter back beyond the range of the hose. A free burning fire reaching an area covered by vegetation not conducive to spreading the fire, kills this vegetation up to a distance of 35 metres. The firefighting method consists of spraying from a point ahead of the fire front so that the radiation cannot vaporise the water on the ground. The fire is thus slowed and can be stopped.

Indirect attack. When smoke and heat make impossible any approach to the fire, or the fire is spreading very fast, or the access to the fire perimeter is difficult, or there exist danger of crown fires or the appearance of spots is important, a fire line is constructed on natural elements on the terrain, including also roads. A fire line contours partially or totally the fire perimeter and its objective is to slow or stop the fire. The calculation of the width of such strap to be effective is critical to achieve this objective. Fire lines are built by crews with manual tools or/and by dozers. The use of chemicals, such as retardants and foams, is quite frequent and effective, either when applied from the air (bombing) or directly from the ground.

Mobilisation and co-ordination of heavy machinery. Heavy machinery is of great use in all cases, but specially in the cases that the fire puts in thread large-forest masses. There are somelimitations in the use of dozers, such as the availability of a certain number in the vicinity of fire area, the time spent in carrying the dozer to the fire edge, status of access lanes and roads onto which the dozers should drive, or the slope and the presence of surface rocks.

Previous to the operation of the dozer, the trees are downed with chainsaws, when such trees are too big for the dozer. The dozer blade is strong enough to remove surface fuel to mineral soil just cutting it at ground level. This are operations of fuel removal needed in large fires, in the construction of fire lines. Besides, dozers are used to widen existing roads thus augmenting their capacity as fire breaks.

Aerial support (water and retardant bombing). The most rapid fire extinction method when there is no dedicated equipment for the protection of selected objectives - such as houses in the forest - consists of fighting the fire from the rear, with successive waves of aircraft proceeding towards the fire head. Besides, water and retardant bombing helps to diminish fire front and flanks linear intensity thus allowing ground crews and fire trucks to operate safely and efficiently.

Some of the well-known aerial fire fighting elements are briefly described below:

Helicopters. Light and medium helicopters (Hughes 500-D Bell 204, 205, 206, Alouette 111 and Ecureuil, among others) equipped with bambi tanks and buckets, are usually added to the initial attack units. Medium-size tanker helicopters (Bell 204 and 205) are also used. The main role of helicopters is to drop water as support to direct attack in difficult conditions of accessibility, and with the ability to pick water in small or inaccessible water points. Together, helicopters are used frequently to rapidly transport material and personnel to areas where accessibility by ground is difficult or impossible.

Super helicopter bombers. Kamov, Erikson Helicrane, Chinook, or Mi-8 helicopters, give an extra power to the most severe cases of fire, dropping water from buckets and tanks of 5 tons up to 9 tons in the case of the Helicrane. Although they have similar characteristics as medium-size helicopters, manoeuvrability is more limited and fuel consumption is high, what entails to allocate a fuel tank in the ground for in-site refilling. The cost of operation of these machines is very high.

Air tankers. These planes are used as small and medium-size water or retardant bombers, and the refill operation is always performed in the airport. The three operations of air tankers, other than surveillance, are support in direct attack, dropping of long-term retardant in indirect attack operations and application of retardant barriers in unburned material. Fast attack tanker aircraft (PZL M-18 Dromaders, Air Tractor AT 802 Focker 27) complete a powerful combination of initial attack resources.

Amphibious scoopers. The amphibious aircraft (CANADAIR CL-215, CL-415) is a scooper that picks up water while skimming over a lake, river, or reservoir, ideally close to the fire. Foam concentrate is injected into the water prior to dropping, thereby enhancing the water's fire fighting effectiveness. Scoopers have proven successful because they can drop suppressants on fires repeatedly, without having to return to base. Scoopers are also generally more manoeuvrable than conventional air tankers due to their wing design and matched power, and generally more accurate due to their lower drop speeds. In the event of a miss, scoopers can reload and return quickly to regain lost ground. Scooping aircraft give fire-fighting agencies a direct attack tool that fills the operational gap when dealing with hard to reach areas, yet they don't require local fixed-base infrastructure. Fixed-wing fire bombing aircraft have several advantages over other types. They can reach the fire quickly with large volumes of suppressant; they can work independently or in support of ground- flit fighters; and, they can deliver a high degree of operational flexibility with a minimal amount of preparation or ground-based support. In aircraft operations, it is important to avoid wasting water drops on the fire's flank. Experience and theory show that when the flank is targeted, multiple aircraft must be used and sent in waves to be effective, rather than using a single aircraft.

Fire extinction modelling

Fire line intensity is related to the type of fire encountered and the required fighting forces that have to be dispatched to successfully content the fire. The general rule can be explained in the following table:

Value of Fileline Intensity in Kcal/m/s	**Fire Fighting requirements**	**Type of fire**
0-80	Fire can generally be attacked at head or flanks by handcrews. Usually the handline should contain the fire.	Low or very low flames and heat. Typical situation of understory prescribed burns. Flame lengths varies from 0 to 1m
80-400	Fires are too intense for direct attack on the head using handtools. Handline cannot be relied to hold the fire. Equipment such as plows, dozers, pumpers and retardant aircrafts can be effective in indirect attack .	Too intense, flame lengths varies from 1 to 2,5 m
400-800	Control efforts at the fire head will probably be ineffective. There is no possibility to reach the fire front closer than 10 m. without serious injuring risk.	Fires are torching out and crowning and spotting may present serious problems
>800	Control efforts at head of fire are ineffective. Flank attack, air bombers and indirect attack are applied where it is possible. It is required to set counterfires.	Crowning and spotting are probable as well as major fire runs

The effect of direct attack is supposed to take place over the fire front section where fireline intensity class has values up to 80 kcal/m/s The effect is expressed in number of cells extinguished per unit time and is derived from the extinction rate tables, expressing the suppressed firefront in meters per hour, considering that one cell corresponds to L meters of firefront, where L is the cell side length. It is assumed that after direct attack in such front section either, speed of fire and intensity are reduced to zero.

The effects of fighting operations in direct attack of firecrews for cells developing intensity below 80 kcal/m/s depend on the local conditions such as fuel model and topography (slope). The suggested table (in meters of suppressed firefront per hour per person) for fire crews are:

Productivity in meter/hour/person

1,2,3	53
4	13
5	53
6,7	40
8,9	26
10	5
11,12	13
13	5

The firefighting trucks efficiency in direct attack operations is calculated using the following table:

1,2,3,8,9	nc.Q. tr /(0,50 R)
4,13	nc.Q. tr /(1,50 R)
5	nc.Q. tr /(0,75 R)
6,7,10,11	nc.Q. tr /(1,00 R)
12	nc.Q. tr /(1,25 R)

where:

- Q is the fire truck tank capacity (litres)
- R is the fire propagation speed at that point (m/min) (XRATE)
- t_r is the residence time of fire at that point (min)
- nc is the number of fighting cycles per hour

The residence time is an intrinsic value that depends on the fuel model considered (tr = 384/C).

The intensity reduction could be estimated through the following expression:

I'B=(C+0.0563)/0.0102613

where C is the concentration of water in litres per square meter

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Bulldozers are used exclusively for defense fireline building to allow effective indirect attack. Their Productivity depends on the engine power and the terrain characteristics. A first productivity approximation table has been widely used (source: 'Bulldozer Fireline Production Rates, 1988'):

Productivity m/h

		Upwards	Downwards	Upwards	Downwards	Upwards	Downwards
< 70	1,2,3,5,8	1267	1770	724	1770	282	1227
< 70	4	443	1187	241	604	60	443
< 70	6	785	1046	443	1247	161	845
< 70	7	785	604	443	1126	161	704
< 70	9,10,11,12 ,13	443	583	241	604	60	221
> 70	1,2,3,5,8	1770	2374	1167	2253	704	1469
> 70	4	644	945	362	1066	101	624
> 70	6,7	1026	1509	523	1569	181	966
> 70	9,11,12	644	945	362	1066	101	624
> 70	10,13	342	463	201	503	60	221

This productivity is considered once the bulldozer is located in the fire area, so previous time lags are considered to be invested in bulldozer turn-on operation (approximately from 30 minutes to 2 hours) and transportation time, computing the carrier truck speed over paved roads (see previous transportation speed tables) and the bulldozer self speed over access lanes in their transportation to the fire area at an average speed of 4 km/h.

The efficiency of the resources using water depends on the distance to the nearest available and suitable water point.

For fire fighting helicopters it is assumed that the total water load is distributed over an effective area of 15x15 m, so the concentration expressed in litres per squared meter is:

$C=Q/15x15$
Again, the intensity reduction could be estimated through the following expression:

$I'_B=(C+0.0563)/0.0102613$
From this value it is an easy task to obtain the intensity class jumps knowing the initially affected intensity. If the reduction is strong enough it can even quench totally the affected area.

The affected area is 15^2 squared meters, so if $A_{cell} = L^2$ is the area of a cell, a proportion could be applied to estimate the number of affected EGU in terms of intensity change:

$N_{EGU} = 15^2/A_{EGU} = 15/L$

thus the total number of affected EGU can be obtained by multiplying this figure by the total number of discharges in the considered time interval. It is important consider that subsequent attacks should reduce the intensity cumulatively.

For air tankers and waterbombers a quite different approach is proposed.

C= f(Q, H cte.)
Q= water load in finders
H=75 m. (discharge flight height is 30 to 120 m.)
$C=1.202+0.00012188Q-12.33294H/Q+2.44962(InQ)/H$
$C2=(C+0.4)/3$ $C3=(CAA)/3$ $Cm--(C+2C3+2C2+2x0.2)/7$
$I'_b=(Cm+0.0563)/0.0102613$

The area affected by the water throwing is A = Q Cm and the same considerations that in the case of helicopters are applied., so:

$N_{cells} = A/A_{cell} = Q\ Cm / A_{cell}$

This calculation corresponds to single air discharges. The total number of discharges per unit time could be obtained knowing the distance to the nearest water point, the water refill time and the average speed of the airborne resource.

Fighting constraints
The operation of forest fire fighting resources is limited to the conditions in which such activities take place, relative to transportation and fire fighting operations. Each fire fighting unit has several operational constraints represented by threshold values for terrain slope, fireline intensity and fire propagation speed and also wind speed and visibility for aerial resources. A table resuming such constraints is given below:

Transportation/Operation Fire Fighting

	Lateral Slope %	**Frontal Slope %**	**Road Width m**	**Road Pavement**	**Wind Speed km/h**	**Visibility Km**	**Fire Line Intesity Kcal/m/s**	**Fire Speed m/min**	**Flame Length m**
Squads							< 80	20	< 1,2
Fire Vehicles	<10	<45	>2	Any			<100	50	<2,4
Carrier Trucks	<5	<15	>12	Asphalt					
Bulldozers	<15	<50	>4	Any			<100	50	<2,4
Helicopters					<60	>10			
Water Bombers					<60	>10			
Air Tankers					<60	>10			

4.- Discussion on the decision trees

We propose to take into consideration the time frame in the decision making according to the developed fire severity.

It is required to identify the critical area Ac for every type of forest fire according to the conditions. This entails a critical time tc beyond which the fire will escape to fighting operations. Decision making must meet this requirement, and all operations have to be carried out within this time frame. Aerial attack is likely to be quicker, but just it has a slowing effect (extending the tc), not an effective suppression, if it is not accompanied of ground attack. If tc is short the decision making must point to deploy forces and strategies for a large fire. In the opposite case, forces can be derived to other existing, more severe fires. To reach tc in time is a fact of -combined planning of forest fuels, surveillance network, ground access network, location of ground and aerial forces and conditions in which fire is initiated and propagated.

5.- Library of pictures of forest fire

A number of pictures of real fires have been obtained in GESTOSA 2001 experimental burnings (Portugal). This is valuable information and a catalogue of surface fires, according to the developed fire intensity, will be finished. Our purpose is to bring intuitive thumb rules to identify the type of fires being developed in the normal chain of fire initiation and consolidation.

A number of pictures of real fires, gathered in the 2000 and 2001 fire campaign, will complement the catalogue. The flame classes will attend to the visual components, such as flame length:

- 400 kW/m, flame length of 1.2 meters
- 1600 kW/m, flame length of 2.5 meters
- 3200 kW/m, flame length of 3.4 meters
- 7000 kW/m, flame length of 4.5 meters

6.- Fire effect, residence time

The fire effect on soil and vegetation depends on two factors mainly

- The developed fire front intensity
- The combustion residence time

The combustion residence time has two components, the flame residence time and the smoldering or slow combustion residence time. The first one depends on (is correlated to) the surface to volume ratio a, which is a value specific of every forest fuel particle type, and thus every forest fuel complex has its own combination of fuel particles (in type and proportion) and the total residence time. The formula linking the two values is:

$t_r = 384/a$

PROMETHEUS project has a complete description of effects of fire on soil and vegetation.

7.- Fire and fire-fighting modelling data requirements

TECNOMA S.A. has a complete digital inventory of Madrid province in Arc/View format (either vector SHP and raster GRD formats). Particular attention has been paid to determining forest fuel types and their distribution, and meteorological-wind patterns.

Several issues are addressed:

- Working frame: analysis area, resolution and format
- Topography
- Forest fuels (we propose to use fuel models, which are parameterised)
- Meteorological data
- Wind data
- Forest fire fighting infrastructures
- Forest fire fighting. resources
    - Fire trucks and personnel
    - Ground tankers
    - Helicopters
    - Air tankers
    - Scoopers