

Guaranteeing safety of animals under risk of fire: conceptual framework and technical issues analysis

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Abstract—The paper introduces the conceptual framework of a Distributed Sensor Network for the monitoring of the wooded areas under risk of fire in the so-called “Vesuvius’ red zone”. Main goal is the determination of the Optimal Evacuation Route for Animals (OPERA) in case of fire, for all the animal species living in the Mount Vesuvius’ surrounding areas, under the perspective of the Disaster Risk Management principles.

Keywords—Fire risk, OPERA, Animal safety, Distributed Sensor Network, Disaster Risk Management

I. INTRODUCTION

According to the 2013 Annual Report of the United Nations office for disaster risk reduction [1] “[...] the devastating impact of forest fires on natural resources was neither quantified nor adequately took into account. Fires are harmful for a number of ecosystem services (whose loss is estimated at around 146–191 Bln dollars per year) including carbon storage, biodiversity support, protection of water sources, reduction of soil erosion, land degradation, and climate regulation”.

In this scenario, the CeRVEnE (Italian acronym for “Regional Veterinary referral Center for non-epidemic emergencies”) was established in 2017 in the Italian Region of Campania, pursuing the objective of the Regional Government to improving and protecting people health through the timely management of both veterinary and non-veterinary epidemic emergencies related to animal health as well as to food safety.

Among the initiatives of CeRVEnE the FRAC Program (Fire Risk Assessment in Campania Region) was presented in 2018, as a project through which the Center intends to provide the Regional Government with a strategic tool able to (i) gathering and supplying in short time all the necessary information to those professionals called to handle fire-related risks, (ii) having a large (both specialized and not specialized) public informed about the operational processes to get started after the fire damages in terms of safeguard and recovery of ecosystems (and related services), wild and domestic fauna, production supply chains, and (iii) figuring out a standardized methodology for gathering data and

supporting decisions consistent with the specifics of the “Disaster Management Cycle” model [2].

II. STATE OF THE ART

A. Disaster Risk Management

The last decades have seen the thriving of the disaster risk management field of study, which includes the total sum of all activities, programmes and measures that can be taken up before, during and after a disaster with the purpose to avoid it, reduce its impact or recover from its losses [3].

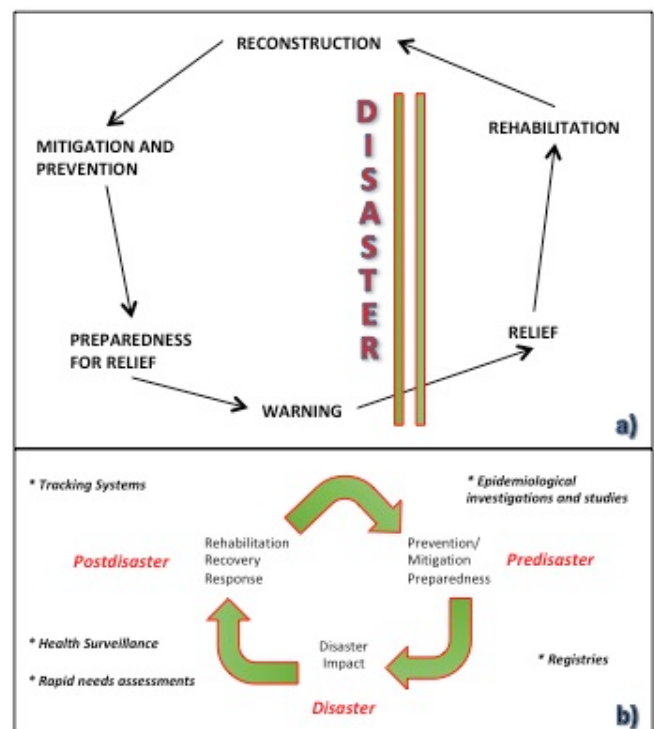


Fig. 1. Disaster Management Cycle (a). Disaster epidemiology actions and the disaster management cycle (b).

Particular interest is then assumed by the concept of “Disaster Management Cycle” (Fig. 1a) that shares isomorphically phases and associated concepts with the linear disaster phase [4–5]. Other scholars [6] also derived the key disaster-related activities employing

epidemiological methods, including rapid needs assessments, health surveillance, tracking systems, epidemiology investigations and studies, and registries (Fig. 1b).

B. Fire risk monitoring

The problem of early detection of fires in forest areas is widely recognized at both national and international level, as witnessed by the European Forest Fire Information System (EFFIS), developed jointly by the European Commission (EC) services (Directorate General Environment and the Joint Research Centre) and the relevant fires services in the countries (forest fires and civil protection services) in response to the needs of European bodies such as the Monitoring and Information Centre of Civil Protection, the European Commission Services and the European Parliament [7].

Furthermore, for what concerns in particular the Mediterranean countries, different technologies are adopted as to the measurement of the relevant parameters for an early fire detection in risky areas: on the one side, the implementation of hierarchical Wireless Sensor Networks (WSN) means the use of a number of sensing nodes that are capable of effectively gathering information from the surrounding environment and communicating with each other to send the measured data to a base station for further processing [8–9]; on the other side, Geographic Information Systems (GIS) can be used to combine different forest-fire causing factors for attaining the forest fire risk zone map. GIS implementation allows the evaluation of a set of parameters that effect the fire, such as topography and vegetation, with the other land use information including population, settlements, forest fire towers, fire stations, intervention places, the characteristics of the staff that will intervene, and transportation: this can make possible for example to figure out the shortest way of intervention during the disaster, and/or the areas to be emptied [10–11].

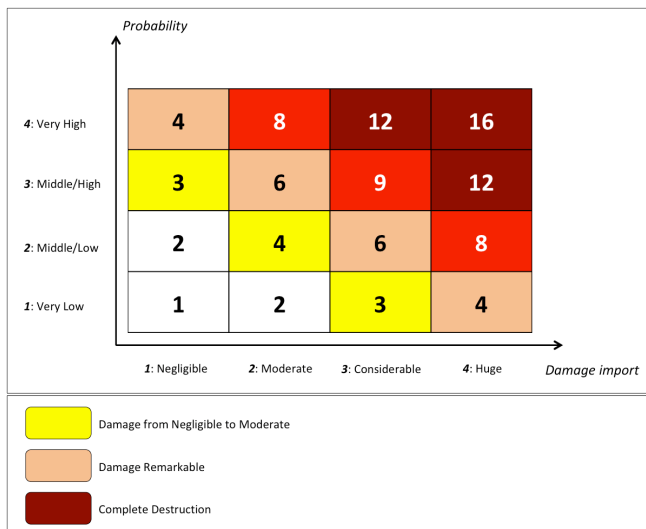


Fig. 2 Fire Risks Assessment Matrix

In line with these actions, within the FRAC program a first extended mapping of the territories surrounding the Mount Vesuvius was performed during the years 2018 and 2019 with a twofold purpose: (i) detect and count all the

farming activities concerning poultry, sheep and goats, cattle, bees, swine, and equines; (ii) figure out a reliable map to classify the different fire risk areas, according to the Fire Risks Assessment Matrix (see Fig. 2) [12–14]

III. PAPER CONTRIBUTION

The present work intends to describe the conceptual framework and to introduce some preliminary results of an IT system to be implemented in order to support the activities pursued by the FRAC Program. In particular, the main scope of the system is twofold, that is on the one side to monitor the wooded areas under risk of fire in the so-called “Vesuvius’ red zone”, and on the other side to determine the OPTimal Evacuation Route for Animals (OPERA from now on) in case of fire, for each of the reported animal species living in the mentioned red zone.

Fig. 3 depicts the necessary steps to accomplish the mentioned goals; in a first moment the gathering of a set of specific information (e.g. Fuel parameters, DEM/Digital Elevation Model Map, ...) is requested to create a *Fire Propagation Map*, through which characteristics and dynamics of a fire episode can be analyzed and evaluated. Starting from this, an *Evacuation Plan Model* can be figured out by also adding anthropic-layered data related to both the urbanization rate and the road system development surrounding the Vesuvius. For both steps, the deployment of specific sensors is required in order to collect the necessary mentioned information. Eventually, in order to determine the *OPERA* such model has to be enriched by means of the mapping of the animal presence (in terms of both typology and distribution) and the clear definition of type and size of vehicles requested to rescue the animal species involved in a fire episode.

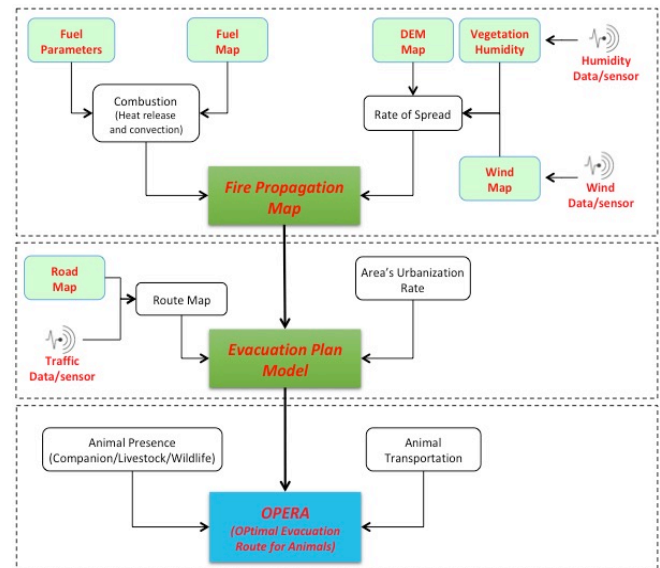


Fig. 3 Particular on the Work methodology

To that end, the software architecture is supposed to integrate a Distributed Sensor Network (DSN) to cover the red zone, an ad-hoc software to generate timely simulation models for predicting the rate of fire spreading [15], and a GIS for both the activities of web mapping and OPERA definition – in particular, the latter step will be performed as

an arborescence optimization problem to be solved for instance via label setting-correcting algorithms. The Unified Modeling Language (UML) graphical notation [16] will be used to figure out the overall process model and to detail its different dynamic and static aspects.

The determination of the OPERA for beekeepers will be analysed as a first-case scenario, in order to provide some preliminary results as to the logic of the system and its working dynamics.

IV. TECHNICAL ISSUES ANALYSIS

Technical issues are mainly related to the realization of a DSN capable of offering early warnings, and eventually monitoring the dynamics of critical events. In the following, the requirements of a network suitable to the purpose are specified and a candidate solution is discussed. The mathematical model underlying the optimization problem is also introduced and formalized.

A. Network requirements

The employment of DSNs for fire detection in forest areas has widely been investigated in the past, highlighting benefits in terms of cheapness and easy deployment [8–9]. Anyway, paying attention to the use of DSN in severe working conditions, such as those related to the presence of fire, several other requirements cannot be jeopardized. One can start enlisting flexibility requirements in terms of integration of sensor terminals, in order to have no constraints at choosing the optimal parameters for the identification of anomalies and the prevention of dangerous situations. Also, no constraints, or at least minor ones, related to the distance between sensor nodes would be of help in order to assure extensive coverage of the monitored area. Another key point is the presence of electric and/or telecommunication infrastructures and the distance of the farthest node from their coupling points. The possibility and costs of maintenance operations represent significant aspects as well. All these factors affect the topology of the network, the design of the hardware for main energy supply systems, as well as of ancillary energy harvesting systems, and sensor equipment. Nonetheless, they deeply impact the choice of the data communication solution.

B. Network architecture

The innovative paradigms enabling Internet of Things (IoT) applications, which are sketched in Fig. 4, seem to offer advantages in both design and implementation of a candidate DSN with respect to more traditional solutions.

The candidate network is essentially made up of two types of nodes, namely sensor and gateway nodes. Each sensor node includes a smart power module, one or more probes, a processing machine, such as the one available in a commercial *BeagleBone* board or else *Raspberry pi* board, and an interfaced wireless transmitter. The electric power module has to supply power to all terminal modules. Electricity demand should also be managed with efficient strategies. The typical sleep/deep-sleep operative modes between data refresh instances are therefore implemented, which involve that all non-critical electronic circuits are disconnected from the power supply except during their

short operative slots. Probes consist of both measurement modules to collect the parameters of interest, such as: relative humidity, temperature, atmosphere pressure, mono and di-oxide carbide (CO , CO_2) percentages, solar irradiance, rain percentage, infrared/ultraviolet radiation intensity, volumetric water content and suction in soil, etc., and detectors for instance for smoke presence, or intruders. It is worth noticing for now that sensor nodes could involve troubles in the implementation of maintenance programs, needed for instance for battery replacement, since they could be distributed in difficult-to-reach places.

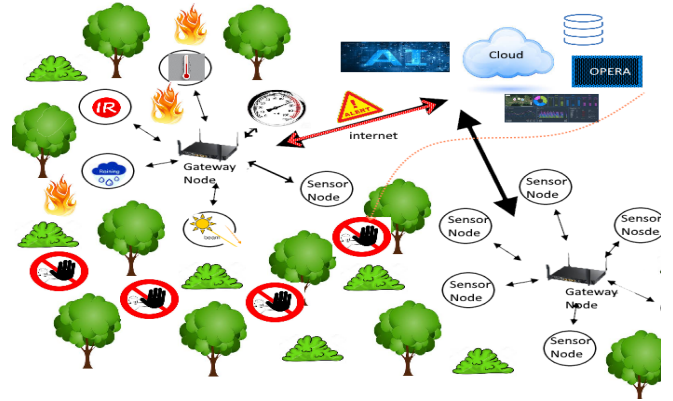


Fig. 4 Schematic representation of a DSN for early detection and monitoring of fire in forest areas, eventually integrated with several facilities made available by IoT solutions.

The processing machine has to deal with both on-site data analyses and data transmission management, as well as with synchronization tasks. It is in fact responsible of assuring reliable data routing to gateway nodes. The availability of a network clock signal is necessary for synchronization purposes: to this end the exploitation of the GPS reference clock is possible by means of a low-cost receiver. Gateways are conceptually different from sensor nodes because their chief role is interconnecting local area networks to the Internet; they require therefore more hardware in terms of processing and memory resources. For the proposed network, each gateway has to merge the data streams transmitted by the dependent sensor nodes, and, in turn, multiplex them into a single mainstream that is transmitted to a general remote collector. Gateways also provide local storage services to temporarily save critical data, thus avoiding information loss in case of occasional connection unavailability. Trading-off between performance and costs, a subset of all gateways of the proposed network is equipped with additional memory resources to assure storage capabilities comparable to those of a secondary database service. A robust implementation consists in distributing the additional memory resources between the gateways of the subset, granting them the possibility of storing a recent history of the mainstreams that should be forwarded to the general collector.

The proposed network is also complemented with a last protected gateway node, operated according to a black box model, that allows post-disaster analysis. Its protection is assured by physically placing the critical parts of its hardware underground. Data transmitted by sensor nodes should not have complex structure, so that traffic between sensor nodes and gateways can be accomplished without

claiming for wide bandwidth resources. Data refresh is therefore programmed at low rate, which is sufficient for regular monitoring. The network is designed such that data refresh is automatically increased during incipient emergencies. Low data rates cope with the low power requirements of long-range wide area networks (LoRaWANs). LoRaWAN is a novel wide range distance communication protocol that is robust to noise and interference, and is capable of offering a coverage radius up to 15 km. Most important, modules compliant with LoRaWANs' specifications require ultra-low power electronic circuits. In addition, they can be complemented with solar, micro-wind, or piezoelectric energy harvesting systems that sustain the state of charge of the supply, which can be made up of both batteries or performant and reliable super-capacitors. The equipment selected for the proposed network adopts a microcontroller board, namely STM32F3DISCOVERY board, which is characterized by reduced power requirements.

Moreover, concerning some constructive details, the use of military chips can increase the resistance to heat so that even in harsh conditions, like those experienced during forest fires, the equipment has still operating time. An IP67 anti-fire package can grant to each sensor node the ability of uninterrupted operation in very hostile environments. Eventually, it has to be added that IoT paradigms generally integrate cloud-computing services, which can be activated on demand by an end customer. The exploitation of cloud resources can simplify storage and computational tasks. In particular, cloud solutions are ideal to produce more consistent, accurate, and useful information than that provided by any atomic systems. Nonetheless, they also represent efficient platforms to implement artificial intelligence (AI)-based approaches, which are becoming important backings to solve very complex problems.

C. Route Optimization

The mathematical modelling of the problem requires the creation of an oriented graph $G = G(N, A)$, whose nodes represent the accessible junctions, while the arks represent the roads that connect two consecutive junctions. For each node the parameter $J_{r,t}$ is defined, where: $r \in [0; M]$ means one specific junction among all the possible M junctions that can be identified once figured out all the possible alternative routes between the starting point and the end point (animal safe zone); $t \in [0; +\infty[$ refers to the time moments for which the discrete simulation of the fire spreading is run. We can have: $J_{r,t} = 0$ (the junction r has already been reached from the fire at the moment t); $J_{r,t} = 1$ (the junction r hasn't been reached from the fire at the moment t yet).

A first set of constraints can be set for each node, which assures that the difference between the whole (road) flow entering the generic node v – ark ($i; v$) – and the whole flow leaving the same node – ark ($v; j$) – corresponds exactly to the requirements of such node (positive difference for the final node; negative, for the starting node; equal to zero, for a transient one). Another set of constraints can be set for each ark, which refers to their capacity, and limits the entity of the (traffic) flow that passes through the ark itself.

The problem of the determination of the OPERA can be therefore figured out as similar to a classic problem of minimum path [17], and consequently expressed in the first place via the following general formula:

$$OPERA = \min \sum_{r=0}^M \sum_{t=0}^{\infty} J_{r,t} \neq 0 \quad (1)$$

V. PRELIMINARY RESULTS

As said, a first-case scenario is introduced, which focuses on beekeepers as the beehives transportation is less problematic in terms of general set up and execution.

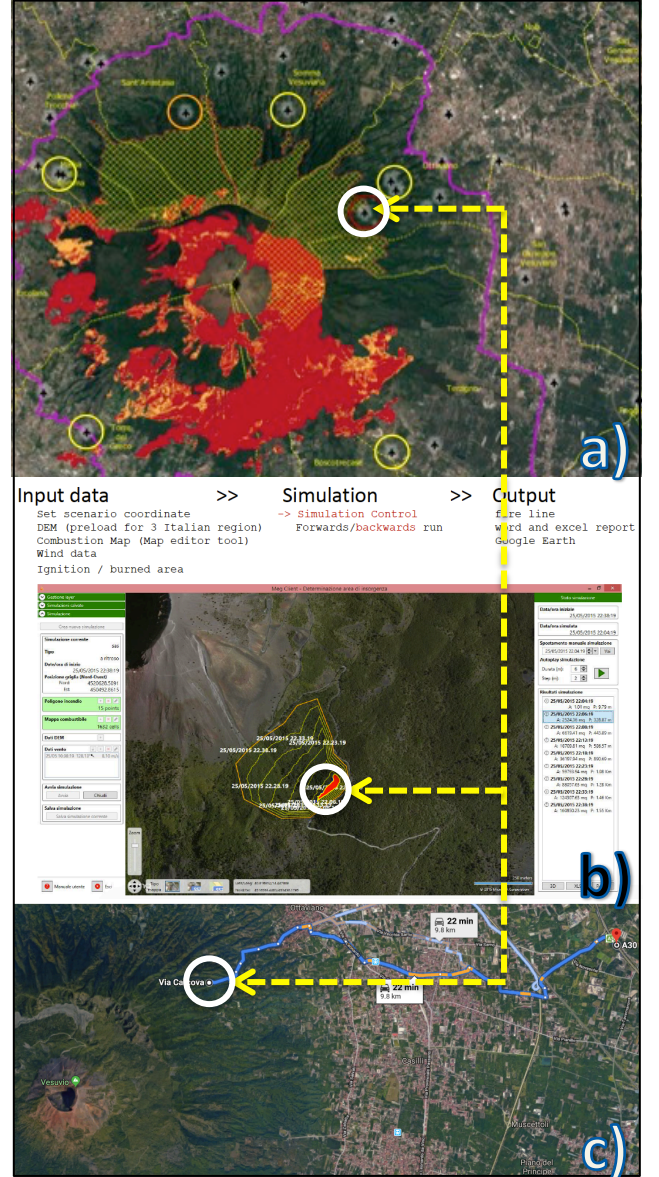


Fig. 5 First implementation of the framework

Fig. 5 reports the three main steps of the simulation, currently still in progress, performed considering a timely not much extended route to get from the starting node on the Vesuvius' slope, up to the safe zone (the A30 highway, in this case), so that a limited number of junctions could be considered. The starting node is represented in Fig. 5a

within a white circle, along with the other beekeepers' sites standing on the territory under consideration, and characterized by different fire risk areas (from yellow to red, in increasing danger level). In Fig. 5b the fire spreading simulation is run, considering the beekeeper's site as the fire source, and the enlarging areas interested by the fire at specific times are calculated from the software. In Fig. 5c the OPERA is "roughly" defined by: (i) identifying in Google Maps © all the alternative routes from the starting point to the safe zone; (ii) overlapping the simulation output to the satellite map, in order to identify, time after time, the junctions not yet interested by the fire; (iii) visualizing each junction-to-junction path, and then manually combining them so as to draw the OPERA for the case study. In particular, the result of (1) was 12.

VI. DISCUSSION AND CONCLUSIONS

The overall system logic is yet to be fully disclosed, as the present paper only describes the conceptual framework of the entire software architecture; nonetheless, the development of the proposed integrated system becomes somehow critical, as the fire risk (and especially arsons risk) has considerably increased in the last years in the whole Mount Vesuvius' surrounding area, which features a unique combination of both animal and anthropic elements within a very delicate natural ecosystem.

The first choice is therefore to design and test the system on a narrow area (the mentioned "red zone") to verify its viability, as in the FRAC Program are actively involved a number of organizations (State Forestry Corps, Local Health Trusts, breeders' associations, up to the very Regional Government) that need to strictly interface with each other – and, in case of fire, in a very short time – in order to build up a solid and efficient system of surveillance planning, risk analysis, and data gathering.

The implementation of a specific integrated system to support the mandate of the FRAC Program is supposed to boost an improvement for the CeRVEnE's activities, pursuant the innovation perspectives coming with the effectual application of the Disaster Management principles.

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REFERENCES

- [1] United Nations Office for Disaster Risk Reduction, "Global assessment report on disaster risk reduction; from shared risk to shared value: the business case for disaster risk reduction", 2013. Retrieved from <http://www.preventionweb.net/english/hyogo/gar/2013/en/home/download.html>
- [2] O. Tamburis, N. Piscopo, P. Reguera Acevedo, R. Bove, F. D'Orilia, R. Pinto, V. Caligiuri, A. Boccia, E. Fiore, L. Esposito, "CeRVEnE prevention systems and assistance plan to wildlife in case of fire disaster", in XI International Symposium on Wild Fauna, Viterbo, Italy, September 2019.
- [3] H. Khan, L.G. Vasilescu, and A. Khan, "Disaster management cycle. A theoretical approach", *Journal of Management and Marketing*, Vol. 6, No.1, pp. 43-50, 2008.
- [4] A. Baird, P. O'Keefe, K.N. Westgate, and B. Wisner, "Towards an explanation and reduction of disaster proneness", Occasional paper no.11, University of Bradford, Disaster Research Unit, 1975.
- [5] C. Coetzee, and D. Van Niekerk, "Tracking the evolution of the disaster management cycle: A general system theory approach", *Jambá: Journal of Disaster Risk Studies*, Vol. 4, No.1, pp. 1-9, 2012.
- [6] J. Malilay, M. Heumann, D. Perrotta, et al., "The role of applied epidemiology methods in the disaster management cycle", *American journal of public health*, Vol. 104, No.11, pp. 2092-2102, 2014.
- [7] J. San-Miguel-Ayanz, E. Schulte, G. Schmuck, et al., "Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS)", in *Approaches to Managing Disaster-Assessing Hazards, Emergencies and Disaster Impacts*, IntechOpen, 2012.
- [8] A. Bayo, D. Antolin, N. Medrano, B. Calvo, and S. Celma, "Early detection and monitoring of forest fire with a wireless sensor network system", *Procedia Engineering*, Vol. 5, pp. 248-251, 2010.
- [9] A. Molina-Pico, D. Cuesta-Frau, A. Araujo, J. Alejandre, and A. Rozas, "Forest monitoring and wildland early fire detection by a hierarchical wireless sensor network", *Journal of Sensors*, 2016.
- [10] E. Erten, V. Kurgun, and N. Musaoglu, "Forest fire risk zone mapping from satellite imagery and GIS: a case study", in *XXth Congress of the International Society for Photogrammetry and Remote Sensing*, Istanbul, Turkey, pp. 222-230, July 2004.
- [11] M.S. Negi, and A. Kumar, "Assessment of increasing threat of forest fires in Uttarakhand, Using Remote Sensing and Gis Techniques", *Glob. J. Adv. Res*, Vol. 3, pp. 457-468, 2016.
- [12] J.M. Watts, "Criteria for fire risk ranking", *Fire Safety Science*, Vol. 3, pp. 457-466, 1991.
- [13] J.M. Watts, "Fire risk assessment using multiattribute evaluation", *Fire Safety Science*, Vol. 5, pp. 679-690, 1997.
- [14] N. Marotta, P.L. Maffei, "L'analisi del valore nella valutazione del rischio incendio", *Ambiente & sicurezza Il Sole - 24 Ore* Pirola, N. 23, 2000.
- [15] W. David, F. Giannino, D. Heathfield, A. Hubervic, A. Aknai, A. Sfetsos, S.E. Piovan, "Giving life to the map can save more lives. Wildfire scenario with interoperable simulations", in *Abstracts of the ICA*, 1, 2019.
- [16] J. Rumbaugh, I. Jacobson and G. Booch, "The Unified Modeling Language User Guide (II ed.)", 2005, Addison-Wesley.
- [17] P.E. Hart, N.J. Nilsson, B. Raphael, "A formal basis for the heuristic determination of minimum cost paths", *IEEE transactions on Systems Science and Cybernetics*, Vol. 4, No. 2, pp. 100-107, 1968.