Chapter 19
FireFight: A Decision Support System for Forest Fire Containment

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Abstract The FireFight project is being developed in collaboration with the GRAF wildland firefighting department (Generalitat de Catalunya, Spain). The main objective is the development of a web-accessible decision support system based on an integrated simulation and optimization framework for optimal wildfire containment. FireFight uses the tooPath (www.toopath.com) web server infrastructure to acquire the broadcasted real-time GPS position of approximately 1,650 land and aerial firefighting resources deployed across the territory. The short-term goal of the project is to help managers in making decisions about the number of extinguishing teams that should be deployed, the design of the water supply chain to bring water and other supplies to the firefighting teams, and the design of the change-of-shift transportation problem.

19.1 Introduction

Forest fires have become increasingly devastating and uncontrollable phenomena and their management is a major issue in Mediterranean countries, where they are an annual occurrence. This situation is certain to worsen with the anticipated impact of climate change and the continuous decline in agricultural land use, which allows the extension and continuity of forested areas to increase. Land abandonment and the cessation of traditional management practices is favoring scrubland and forest expansion throughout Europe, reducing the extent of many semi-natural open habitats of a high ecological value [1]. Figure 19.1 shows a typical map of forest fire risk during the summer period in the Catalonia region (north east of Spain); most of the land has a medium to extreme risk of forest fire.

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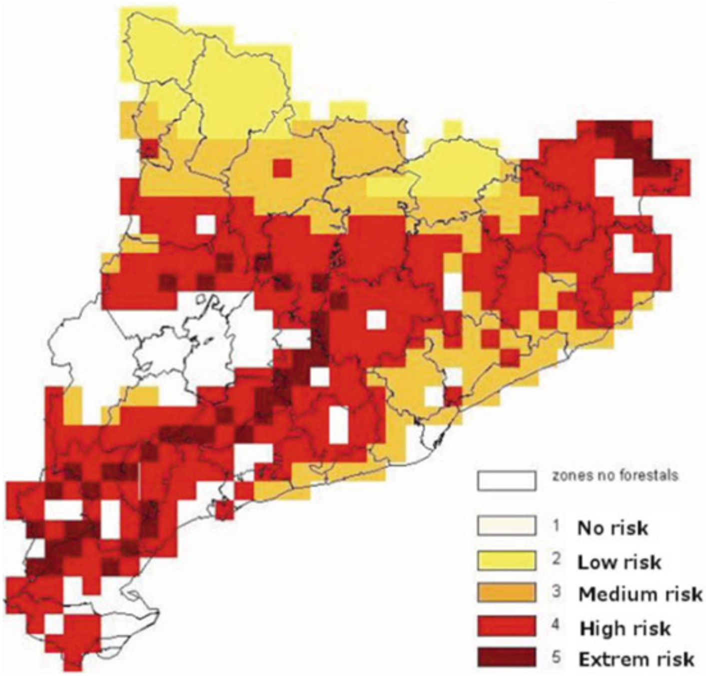

Fig. 19.1 Map of forest fire risk, August 2012 (Source: Generalitat de Catalunya)

The management of these fires is a serious concern for many governments around the world, and responsibility for decisions regarding containment falls to specialist wildfire managers; in the event of a reported wildfire, they select which of the firefighting resources at each base station should be dispatched to the fire site, establish a plan of action, and determine the firefighting tactics that should be employed. Taking such decisions is difficult due to the time constraints, the dynamic and uncertain behavior of fires, and the limited availability of firefighting resources. Correct decision-making is crucial for saving lives, property and natural resources.

In Catalonia, forest fire decisions are taken by the GRAF team lead by Marc Castellnou. The GRAF team is a group within the firefighting department of the Government of Catalonia and is responsible for preventive actions as well as resource deployment and attack. A typical preventive action is the burning of specific areas in winter to prevent excessive connectivity of large forest areas.

Fuel treatment of the wildland-urban interface is an approach that can mitigate the risk of fire propagation through urban or residential areas [2]. In 2003, Law 5/2003 was passed in Catalonia laying down mandatory measures for residential and rural buildings designed to prevent forest fires. A summary of these regulatory measures is given below:

- Buildings must be surrounded by a protective perimeter at least 25 m wide, cleared of shrubs and with reduced tree fuel.

- Plots within the protective perimeter must be cleared of dry vegetation.
- Residential areas must have a network of approved fire hydrants.
- An approved self-protection plan must be in place in these areas.

Unfortunately, not all wildland-urban interfaces are protected by a cleared perimeter, and the problem is worsened by the reduction of resources devoted to wildfire protection and the continued expansion of the wildland-urban interface. In large wildfire scenarios affecting urban areas or isolated farms, the decision-making process is a critical task with potential repercussions on human life and property. The ability to predict fire spread behavior and to evaluate the impact of alternative tactics is crucial to decision-making for wildfire containment [3].

FireFight is an ongoing project concerned primarily with the development of a decision support system (DSS) based on an integrated simulation and optimization framework for optimal wildfire containment.

19.2 State of the Art

Modeling wildfire and the related containment processes is not an easy task due to the inherent complexity of the different processes involved. As such, various efforts to model wildfires have focused on one or more specific aspects of the phenomenon. However, the most obvious element to be modeled is fire propagation across the landscape. Some theoretical approximations involve the use of operations research techniques to model fire behavior [4–6]. In these approaches, the representation of wildfire behavior is generated taking into account landscape, wind and many other factors that can affect a fire's movement. The modelling of individual wildfire factors is often challenging due to their specific complexities, as is the case of wind, which has been the focus of several studies, in particular [7, 8], which present local descriptions of wind behavior for risk areas in Wales and the Netherlands. Other factors have also been the focus of specific studies. Thus, [9] presents a model for determining the probability of fire occurrence in forest stands of Catalonia, and [10] proposes the Dynamic Fire Risk Index (DFRI), which establishes the risk of fire occurrence on the basis of different static and dynamic factors.

All of these models rely heavily on the availability of accurate data, so it is necessary to verify the correctness of the data fed into the model as well as ensuring the early detection of the phenomenon. In this sense, notable studies include [11], on early detection, and [12], on the mapping of possible and probable fires and the retrospective modelling of past forest fire scenarios. An interesting study that considers the problems deriving from low visibility due to cloud cover was published by [13].

However, these theoretical models do not take into account the containment process. If a complete description of the phenomenon is needed and several alternatives for the containment process are considered, a holistic approach is required. In this case, it is necessary to have not only a robust model for representing the fire behavior but also a model for representing resource allocation and containment strategy.

Existing infrastructures for representing wildfire behavior and containment include FARSITE [14], a fire behavior and growth simulator used by the USDA FS, USDI NPS, USDI BLM, and USDI BIA Fire Behavior Analysts. It is designed for use by planners and managers familiar with fuels, weather, topography, wildfire situations, and the associated concepts and terminology. FARSITE and other simulation tools such as HFire [15], Prometheus [16] and SiroFire [17] focus heavily on the representation of fire evolution, although they also offer some capabilities for representing fire containment.

Systems that focus more specifically on containment include the proposal of [18], who present a unified framework based on a mathematical programming formulation that integrates various decisional problems arising in the management of different kinds of natural hazards. Donovan and Rideout [19] analyzes how the resources needed for the containment process can be optimized using integer programing. Although this approach is powerful, certain limitations have led to the examination of other alternatives, such as the use of stochastic simulation [20]. SIADEX [21] comprises four main components: a web server, which centralizes the flow of information between the system and the user; the planning and monitoring servers, which are offered as intelligent services through the web server; and the ontology server, for sharing and exchanging knowledge between all components. Hu and Ntaimo [3] presents a stochastic mixed-integer programming model for initial attack to generate firefighting resource dispatch plans using as input fire spread scenario results from a standard wildfire behavior simulator. The same study also presents an agent-based discrete event simulation model for fire suppression, used to simulate fire suppression based on dispatch plans from the stochastic optimization model.

The use of Multi-Agent Simulation (MAS) to represent containment has also been explored by [22], who propose a model for coordinating teams of computational agents that can be used for different domains but is specifically applicable to forest firefighting. The model is based on Pyrosym [23]. MAS has been also been used to represent evacuation under fire conditions [24].

The use of formal languages to model wildfire behavior is a promising recent development. A model to represent wildfire propagation, using a formal representation of a cellular automaton based on DEVS, is presented in [5]. Ntaimo [25] presents DEVS-FIRE, which also uses DEVS as a formal language to represent the phenomenon. DEVS-FIRE can be integrated with a stochastic optimization model to determine the optimal firefighting resources to dispatch to guarantee wildfire containment in the shortest possible time and with minimal cost. Other studies of DEVS for representing the wildfire phenomenon include [26], which presents an interesting combination of Cell-DEVS with CD++ [27] to reduce the algorithmic complexity for the modeler, enabling the use of complex cellular timing behaviors and different Cell-DEVS quantization techniques to decrease execution time. Similar approaches to reduce the inherent complexity of this kind of simulation can be reviewed in [28]. Other formal languages have been used to represent wildfire phenomenon, like Specification and Description Language [29]. One of the main issues that must be addressed in this type of approach is how to represent the environment with the selected formalism, which often entails the representation of cellular automaton structures. Fonseca i Casas et al. [30] presents a method for using SDL to formally represent cellular automaton structures and specifically a wildfire propagation model. Gronewold and Sonnenschein [31] explains how to model cellular automaton structures using Petri nets.

Finally, it is interesting to note studies that focus on validation and verification. Niazi et al. [32] presents the verification and validation of an agent-based model of forest fires using a combination of a Virtual Overlay Multi-Agent System (VOMAS) validation scheme with Fire Weather Index (FWI) to validate the forest fire simulation.

19.3 FireFight Architecture

The proposed experimental environment project architecture is shown in Fig. 19.2. Its principal component is an optimizer that uses fire spread and contention simulations to determine the best fire attack strategy for a particular scenario. The main processes and outputs of the FireFight system are as follows:

Web GUI and tracking server: Designed to facilitate user interaction with the FireFight system. Two different operational modes are provided: a training or evaluation mode that uses an on-line fire spread simulator to generate different evaluation scenarios; and a real-time mode intended to support the management of ongoing wildfires.

Fire & logistics scenario: A simulated wildfire scenario consists of the information defined by [33]. This information is read by the GUI, which tells the controller to generate the scenario from the geospatial database. An ongoing wildfire scenario is monitored via data and other relevant information obtained from field sensors (i.e. GPS data) and from firefighting personnel.

Controller: Synchronizes the different application processes.

On-line fire spread simulator: Simulates a real fire, applying the best tactics proposed by the optimizers. This tool is intended for training and evaluation using models of real fires or hypothetical fire scenarios.

Optimizer: Searches for the best feasible solutions from a set of fire suppression tactics and decisions using the resources available in a particular scenario.

Feasible plans: The set of feasible solutions found by the optimizer which must be simulated in order to evaluate their potential outcomes.

Best plan: The best of the feasible solutions proposed by the optimizer, which must be implemented by the firefighters. This solution is used by the reality simulator.

Fire spread and containment logistics simulator (proposed plans): Evaluates the impact of the proposed containment logistics decisions (feasible plan) proposed by the optimizer.

Results: The output of the fire spread and containment logistics simulator for the proposed plans. These results are used by the optimizer to search for a good solution.

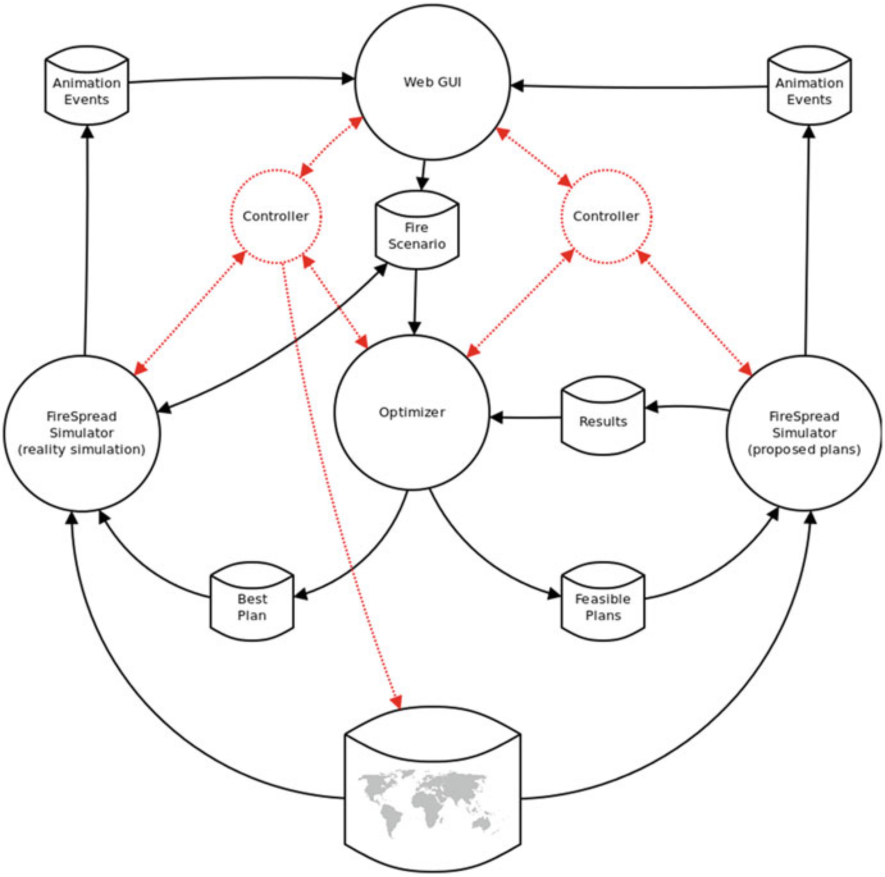

Fig. 19.2 FireFight architecture

The FireSpread simulator is currently being used offline by the GRAF team to predict fire evolution. Analysis of the simulation identifies an anticipated active fire line that is fed into the optimizer to determine the best plan for the deployment of containment resources.

19.3.1 Web GUI and Tracking Server

Personnel portable GPS devices became mandatory in Catalonia for all firefighting teams following recommendations issued after the Horta de Sant Joan fire of July 2009, during which five GRAF elite firefighters died when trapped by fire, despite the deployment of a last resort fire shelter, consisting of an aluminum blanket that protects against flames and heat.

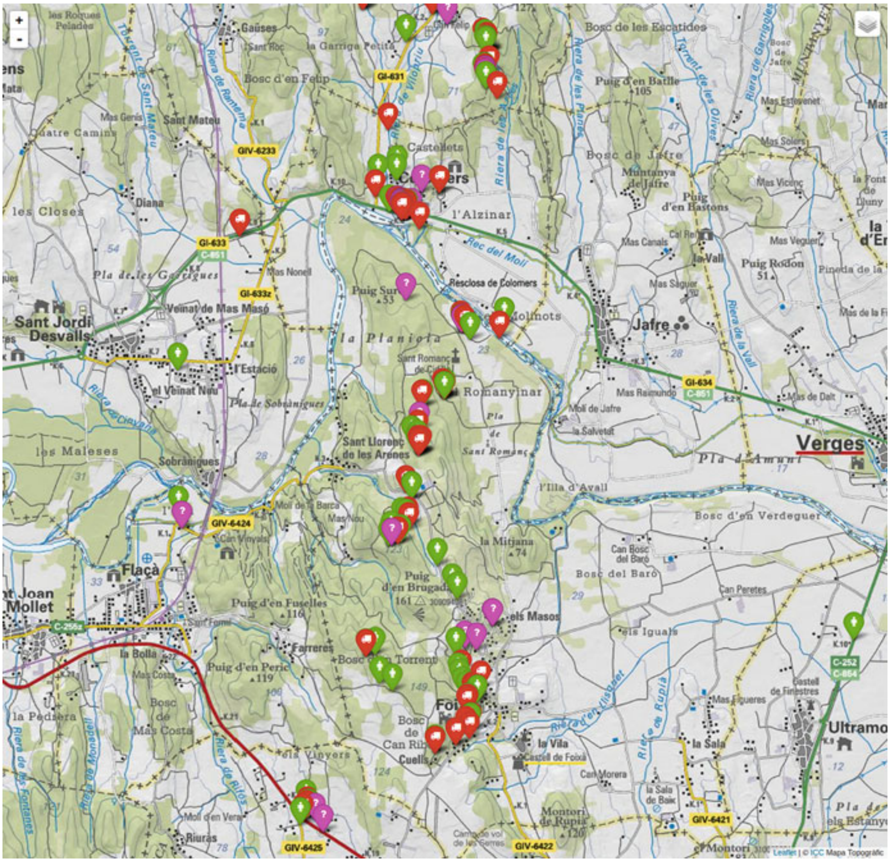

Fig. 19.3 GPS location of Baix Emporda fire resources (November 12th, 2013, 8:34 a.m.)

In Catalonia, all aerial and ground firefighting resources are now located and tracked by GPS. According to the latest figures, 1,650 GPS devices currently send information to the location servers. Figure 19.3 shows the position of all resources deployed for a wildfire on November 12th, 2013. This information is also broadcast in real-time to our tooPath (www.toopath.com) tracking server.

GPS data is a valuable source of information for real-time decision making and post-fire analysis. The effective use of this information is a key focus for future research and development in the area of DSS for wildfire containment logistics.

The containment effectiveness of each ground firefighting team depends on natural factors such as vegetation density, vegetation type and topography, and logistic factors such as the availability of aerial resources. One of our first goals is the systematic analysis of the GPS data in order to obtain real measures of the effectiveness of the attack force. A containment table for initial attack effectiveness has already been proposed [34], and our analysis will expand on current results with a focus on Mediterranean forest fires.

19.3.2 Fire Spread Simulation

Prescribed burning is commonly used in the management of fire-prone vegetation in order to create fuel breaks which may reduce the occurrence of large-scale wildfires [35, 36]. Therefore, when firefighting resources are scarce it is very important to select the most appropriate locations for fuel breaks. One possible approach for selecting the location of fuel breaks is to use fire spread simulations. For example, [37] propose a simulation-optimization approach where a stochastic simulation of fire spread estimates the fire risk of each solution proposed by a metaheuristic search algorithm.

The GRAF firefighting team of the Government of Catalonia uses Wildfire Analyst (http://tecnosylva.com) software to predict fire spread. Offline stochastic simulation sensitivity analysis is used to predict the future behavior of each fire, taking into account the dominant wind in each area of the territory. The team uses the simulation results and its own expertise to build a Fire Propagation Graph (FPG) for each dominant wind situation in all forest areas across the Catalonia region. The FPG is used in two complementary ways:

- FPG connectivity analysis is used to decide where to execute off-season prescribed burning in order to reduce the fuel load in specific arcs of the graph, thus lowering the probability of large-scale wildfires.
- FPG connectivity analysis is also used for real-time decision making when the wildfire is active. The FPG is used in combination with the expected evolution of the fire obtained by simulation with the current meteorological information to determine where to place the extinguishing resources. The decision is not always to minimize the spread of the fire; the protection of urban areas is usually considered a priority, even at the cost of further fire growth.

Dynamic real-time access to fire information is a vital element for controlling wildfires. Fire managers who respond to wildland fire outbreak need regular updates on the state of the fire. Details of the active fire fronts are therefore crucial because they can be used to estimate how fast the fire is moving and to predict where the fire is likely to spread in the future [38]. The anticipated active fire line is used for tactical-level decision-making.

19.3.3 Containment Optimization

Strategic planning is designed to minimize the loss and suffering associated with wildfires by preventing fire outbreaks. Strategic planning also encompasses decisions related to the fire season as a whole. Once a forest fire has broken out, however, tactical-level decisions are needed to bring the fire under control [25]:

1. Strategic decisions: How much money should be spent on forest fire management each year? How many aerial devices should be used and where should they be

placed? How many firefighting teams should be hired? Where should preventive actions be carried out off-season? How should the firefighting teams and aerial resources be deployed each day? When and where should special preventive measures like restricted fire zones and restricted travel zones be invoked?

2. Tactical decisions: How many firefighting and aerial resources should be allocated to a specific fire? Where should ground resources be placed? How many water trucks are needed to replenish each fire water truck?

19.4 Decision Support System Development

A DSS is a computer-based information system that supports decision-making activities [39]. The FireFight project can be classified as an active DSS [40] providing assistance based on a model-driven DSS [41].

An active DSS is a support system that is capable of providing decision suggestions or solutions to different problems without subsequent feedback or refinement from the advisor in charge of the decision-making process. As described in Sect. 19.3.3, the decision suggestion is processed by an optimizer that provides best solutions, thus if no additional data are provided the optimizer cannot refine its search. To overcome the limitations of an active DSS relative to a cooperative DSS, the solutions are recalculated at regular intervals taking into account newly received data.

A model-driven DSS generates suggestions and solutions on the basis of simulation and optimization models. As described in Sects. 19.3.2 and 19.3.3, FireFight DSS uses a fire spread and containment simulator to simulate fire propagation during a fire event and an optimizer to calculate feasible and optimal solutions.

19.4.1 Optimization in FireFight DSS

There are three problems the DSS must solve. The main problem is optimizing the deployment of extinguishing teams, which are composed of an engine and an engine crew. The second problem is ensuring a supply of water and equipment to each engine. The third problem is relieving each engine crew at the end of every operational period (usually 24 h) with new crews arriving from all over the territory.

19.4.1.1 Deployment Optimization

The deployment optimizer determines the best way to contain the fire by answering the following questions: How many engine crews are needed to contain the fire by a specific date/time? What is the outcome of increasing or decreasing the number of crews? Where can crews be placed, taking into account the road/path/trail network, the fire expected evolution, the topography and the cartography?

The answers are calculated taking into account the fire-spread simulation, the topography, the land-cover vegetation and the road/path/trail network. With this information and the GPS tracking data, the DSS calculates the wet-line containment crew speed, enabling the optimizer to determine the optimal deployment.

19.4.1.2 Supply Chain Design

The DSS system designs the water supply chain to ensure that each fire truck has a continuous supply of water. In configuring the design, the following questions must be answered: How many water supply trucks are needed for each extinguishing team, given a geographical distribution of water depots? How many additional tankers or engines are needed to refill finite capacity water depots?

Exact data on water consumption by firefighter crews are unavailable and must therefore be estimated by interpolating historical data on wet-line containment crew speed.

19.4.1.3 Shift Changes Between Operational Periods

The FireFight DSS has to calculate how each of the different crews are replaced with new crews for another operational period. The change-of-shift problem arises because the firefighting vehicles used to transport the crews are located at the site of the wildfire and cannot move from there, hence other resources are needed. In Catalonia, temporary transport is provided by the police, so the DSS has to answer the following questions: How many police cars are needed to pick up 'fresh' fire crews teams from geographically distributed fire stations and bring them to the fire? Are they enough to return the firefighters finishing their shifts to their base stations? What route and timetable should each car follow in order to deliver fire crews to the site on time?

This problem is modeled as a VRP problem with time windows and capacity constraints. Although it is similar to the school bus problem (SBP), this particular optimization problem does not take into account the return of the crews ending their shifts to their base stations, the time of which must be minimized.

19.5 Conclusions

This article focuses on the architecture and approaches for optimizing the solutions to different problems in the emergency management of a wildland fire and presents the FireFight experimental environment architecture for planning optimal deployment and management for wildfire containment and suppression. The system will use real data from different sources. The optimization and simulation framework uses standardized information to ensure interoperability with different systems. The use of different simulators to represent the current state and forecasted state of the fire makes the system robust to changes and enables the optimizer to adapt to new realities. This study and the improvements it reports are being developed in conjunction with the firefighting department of the Government of Catalonia, with the aim of solving problems present in the wildland firefighting workflow.

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References

1. Ascoli D, Lonati M, Marzano R, Bovio G, Cavallero A, Lombardi G (2013) Prescribed burning and browsing to control tree encroachment in southern European heathlands. For Ecol Manage 289:69–77. doi:10.1016/j.foreco.2012.09.041
2. Syphard AD, Keeley JE, Brennan TJ (2011) Comparing the role of fuel breaks across southern California national forests. For Ecol Manage 261(11):2038–2048. doi:10.1016/j.foreco.2011.02.030
3. Hu X, Ntaimo L (2009) Integrated simulation and optimization for wildfire containment. ACM Trans Model Comput Simul 19(4):1–29. doi:10.1145/1596519.1596524
4. Andrews P (2007) BehavePlus fire modeling system: past, present, and future. … of 7th symposium on fire and forest meteorology. Retrieved from http://www.researchgate.net/publication/8400756_Diving_ability_of_Anopheles_gambiae_(Diptera_Culicidae)_larvae/file/9fcfd4ff51c851cff4.doc
5. Innocenti E, Santucci J, Hill DRC, Cnrs IUMR, Cedex A (2004) Active-DEVS: a computational model for the simulation of forest fire propagation *
6. Rothermel RC (1983) How to predict the spread and intensity of forest and range fires. Boise, Idaho, p 166
7. Luo W, Taylor M, Parker S (2008) A comparison of spatial interpolation methods to estimate continuous wind speed surfaces using irregularly distributed data from England and Wales. Int J Climatol 959:947–959. doi:10.1002/joc
8. Luo W, Taylor M, Parker S (2004) Spatial interpolation for wind data in England and Wales, University of York. doi:10.1002/joc.1583
9. González JR, Palahí M, Trasobares A, Pukkala T (2006) A fire probability model for forest stands in Catalonia (north-east Spain). Annals For Sci 63(2):169–176. doi:10.1051/forest:2005109
10. Hernández-Leal PA, González-Calvo A, Arbelo M, Barreto A, Alonso-Benito A (2008) Synergy of GIS and remote sensing data in forest fire danger modeling. IEEE J Sel Top Appl Earth Obs Remote Sens 1(4):240–247, Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4703188
11. Pennypacker C, Jakubowski M, Kelly M, Lampton M, Schmidt C, Stephens S, Tripp R (2013) FUEGO – fire urgency estimator in geosynchronous orbit – a proposed early-warning fire detection system. Remote Sens 5(10):5173–5192. doi:10.3390/rs5105173
12. Carvalheiro LC, Bernardo SO, Orgaz MDM, Yamazaki Y (2010) Forest fires mapping and monitoring of current and past forest fire activity from meteosat second generation data. Environ Model Software 25(12):1909–1914. doi:10.1016/j.envsoft.2010.06.003
13. Chladil M, Nunez M (1995) Assessing grassland moisture and biomass in Tasmania – the application of remote-sensing and empirical-models for a cloudy environment. Int J Wildland Fire 5(3):165. doi:10.1071/WF9950165

14. Finney M (1994) FARSITE: a fire area simulator for fire managers. In: The proceedings of the Biswell symposium, pp 55–56 . Retrieved from http://www.firemodels.org/downloads/farsite/publications/Finney_1995_PSW-GTR-158_pp55-56.pdf
15. Morais ME (2001) Comparing spatially explicit models of fire spread through chaparral fuels: a new algorithm based upon the Rothermel fire spread equation. Retrieved from http://firecenter.berkeley.edu/hfire/hfire_fire_spread_body.pdf
16. Tymstra C, Flannigan MD, Armitage OB, Logan K (2007) Impact of climate change on area burned in Alberta's boreal forest. Int J Wildland Fire 16(2):153. doi:10.1071/WF06084
17. Chi S, Lim Y, Lee J, Lee J (2003) A simulation-based decision support system for forest fire fighting. AI* IA 2003: advances in ..., 2013. Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-39853-0_40
18. Minciardi R, Sacile R, Trasforini E (2009) Resource allocation in integrated preoperational and operational management of natural hazards. Risk Anal 29(1):62–75. doi:10.1111/j.1539-6924.2008.01154.x
19. Donovan G, Rideout D (2003) An integer programming model to optimize resource allocation for wildfire containment. For Sci 49(2):331–335, Retrieved from http://www.ingentaconnect.com/content/saf/fs/2003/00000049/00000002/art00017
20. Fried JS, Gilless JK, Spero J (2006) Analysing initial attack on wildland fires using stochastic simulation. Int J Wildland Fire 15(1):137. doi:10.1071/WF05027
21. de la Asunción M, Castillo L, Fernámdez-Olivares J, García-Pérez O, González A, Palao F (2005) SIADEX: an interactive knowledge-based planner for decision support in forest fire fighting. AI Commun 18(4):257–268, Retrieved from http://dl.acm.org/citation.cfm?id=1218883.1218887
22. Moura D, Oliveira E (2007) Fighting fire with agents – an agent coordination model for simulated firefighting. In: Proceedings of the 2007 spring simulation multiconference, vol 1, pp 71–78. Retrieved from http://dl.acm.org/citation.cfm?id=1404680.1404691
23. Sarmento LM (2004) An emotion-based agent architecture. Retrieved from http://paginas.fe.up.pt/~niadr/PUBLICATIONS/thesis_Masters/LuisSarmento.pdf
24. Yi S, Shi J (2009) An agent-based simulation model for occupant evacuation under fire conditions. In: 2009 WRI global congress on intelligent systems, IEEE, pp 27–31. doi:10.1109/GCIS.2009.442
25. Ntaimo L (2004) Forest fire spread and suppression in DEVS. Simulation 80(10):479–500. doi:10.1177/0037549704050918
26. Muzy A, Innocenti E, Aiello A, Santucci J-F, Wainer G (2002) Cell-DEVS quantization techniques in a fire spreading application. In: Proceedings of the winter simulation conference, vol 1. IEEE, pp 542–549. doi:10.1109/WSC.2002.1172929
27. Wainer GA (2004) Modeling and simulation of complex systems with Cell-DEVS. In: Ingalls RG, Rossett MD, Smith JS, Peters BA (eds) Proceedings of the 2004 winter simulation conference
28. Yang J, Chen H, Hariri S, Parashar M (2005) Self-optimization of large scale wildfire simulations. Computational Science–ICCS ..., pp 615–622. Retrieved from http://link.springer.com/chapter/10.1007/11428831_76
29. ITU-T. (2011) Specification and description language – overview of SDL-2010, p 68
30. Fonseca i Casas P, Colls M, Casanovas J (2010) Towards a representation of environmental models using specification and description language-from the fibonacci model to a Wildfire Model. In: KEOD. Retrieved from http://upcommons.upc.edu/handle/2117/11032
31. Gronewold A, Sonnenschein M (1998) Event-based modelling of ecological systems with asynchronous cellular automata. Ecological Modelling, 18. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304380098000179
32. Niazi Ma, Siddique Q, Hussain A, Kolberg M (2010) Verification & validation of an agent-based forest fire simulation model. In: Proceedings of the 2010 spring simulation multiconference on – SpringSim'10, 1. doi:10.1145/1878537.1878539

33. Nader B, Filippi J, Bisgambiglia P (2011) An experimental frame for the simulation of forest fire spread. In: Jain S, Creasey RR, Himmelspach J, White KP, Fu M (eds) Proceedings of the 2011 winter simulation conference, pp 1010–1022. Retrieved from http://dl.acm.org/citation.cfm?id=2431637
34. Bratten FW (1978) Containment tables for initial attack on forest fires. Fire Technol 14(4):297–303. doi:10.1007/BF01998389
35. Beaumont KP, Mackay DA, Whalen MA (2012) The effects of prescribed burning on epigaeic ant communities in eucalypt forest of South Australia. For Ecol Manage 271:147–157. doi:10.1016/j.foreco.2012.02.007
36. Stephan K, Kavanagh KL, Koyama A (2012) Effects of spring prescribed burning and wildfires on watershed nitrogen dynamics of central Idaho headwater areas. For Ecol Manage 263:240–252. doi:10.1016/j.foreco.2011.09.013
37. Rytwinski A, Crowe KA (2010) A simulation-optimization model for selecting the location of fuel-breaks to minimize expected losses from forest fires. For Ecol Manage 260(1):1–11. doi:10.1016/j.foreco.2010.03.013
38. Fei Y, Xianlin Q, Bo H, Xi Z, Zengyuan L (2013) 1 . Automatic extraction of active fire line using Landsat imagery. In: Proceedings of dragon 2 final results and dragon 3 kick-off symposium, Noordwijk, p 649
39. Keen PGW (1980) Decision support systems: a research perspective. Cambridge, Massachusetts: Center for Information Systems Research, Afred P. Sloan School of Management. Retrieved from http://hdl.handle.net/1721.1/47172
40. Haettenschwiler P (1999) Neues anwenderfreundliches Konzept der Entscheidungsunterstützung. In: Gutes Entscheiden in Wirtschaft, Politik und Gesellschaft. vdf Hochschulverlag, Zurich, pp 189–208
41. Power DJ (1997) What is a DSS? DSstar, 21 October 1997, 1(3). http://dssresources.com/papers/whatisadss/index.html