BUILDING AN INNOVATIVE SOLUTION FOR WILDFIRE PREVENTION AND MANAGEMENT: THE "AEGIS" PLATFORM

TRACK: MANAGEMENT AND ORGANIZATIONAL ISSUES IN INFORMATION SYSTEMS

Abstract

The Web wildfire prevention and management information system AEGIS is currently under development aiming to reduce potential human, environmental and property losses. AEGIS leverages advanced capabilities of Geographic Information Systems (GIS) (like parallel processing in the Cloud and utilization of artificial neural networks) through a user-friendly web interface, without the need for extensive training on commercial or complicated GIS applications. This work describes the analysis of the requirements procedure followed for the development of AEGIS. Emphasis is given on how different user groups can be identified and how their opinion can be taken into account to enhance the usefulness of the proposed system. The methodology described can be used as a framework in the development of forest fire management systems.

Keywords: *wildfires, Web-GIS, requirements analysis*

1. INTRODUCTION

In Greece, wildfires constitute the most devastating natural disasters along with floods and earthquakes. The current operational wildfire danger rating system is based on a qualitative semi-empirical approach. In addition, fire simulation during a wildfire event are not easily utilized by the fire departments that are responsible for the confrontation of each event. On the other hand, a wildfire management system including fire danger assessment and fire simulations cannot rely on methodologies that have been developed *per se* for other countries, because they do not take into consideration the local particularities of the Greek climate, vegetation, topography and human geography.

Within this context, the AEGIS system was designed to appear as a cost effective, easy-to-use forest fire management system, independent of commercial software for the end-users. The main functionalities of the system are a fire danger rating system and a fire behavior modelling scheme. The structure of the algorithms will be based on parallel computer processing techniques to ensure both scalability and efficiency of the calculations.

The scope of this paper is to present the requirements analysis of the AEGIS system. Research experience in the utilization of wildfire prevention systems (Grasso and Singh, 2009; Barber et al., 2010; Chuvieco, 2004; Davies et al., 2009; Fiorucci et al., 2008; Lee et al., 2002) as well as in the development of web-based GIS platforms for forest fire control (Kalabokidis et al., 2012), ontology-based geo-portals for wildfires (Kalabokidis et al., 2010; Kalabokidis et al., 2011) and the development of wildfire applications in the Cloud (Kalabokidis et al., 2014) is a valuable asset towards the requirement analysis of the platform. Users have the ability, without the requirement of knowing the handling of complicated fire management systems, to integrate fire science models and decision support planning modules and to utilize the capabilities of the system. Artificial neural networks and innovative geospatial tools are utilized, while advanced propagation algorithms are used for fire behavior modeling and mapping including burning consequences.

Furthermore, the goal-modeling representation was used for conducting the analysis of the functional and non-functional requirements of the system under development in order to conduct the mapping and proper analysis of the main organizational and functional goals into respective sub-goals as well as system processes.. Finally, all use cases along with the respective user groups are identified and presented with UML diagrams.

Based on the importance of requirements analysis stage and the knowledge IT professionals should acquire for the system to realize all organizational and functional goals, the paper is structured on a respective manner following the analysis process. Specifically, in Section 2 the AEGIS platform is presented, while the goal-process model of the AEGIS platform is presented in Section 3. The goals and the respective sub-goals are derived from the aforementioned description for the system under development. . In Section 4, the end-user requirements analysis is presented. Specifically, for verifying the usefulness of the proposed system from key user groups a questionnaire was decided for taking the input on the requirements of the system. In Section 5, the respective use cases are presented. All user categories along with the group of services that they can access are presented using UML diagrams. In Section 6, the architectural components of the system are presented. Finally, Section 7 concludes the paper and raises points for future development.

2. THE AEGIS PLATFORM

The AEGIS application is designed and implemented as a web-based platform and provides access to fire prediction data (risk and behavior), as well as additional information such as socioeconomic activities, roads, land uses, water tanks locations, patrol routes, fleet tracking, satellite images, vegetation types, terrain and weather data. All functionalities provided by AEGIS are accessible to the local fire agencies and authorities of civil protection through an appropriate graphical user interface. Without any special knowledge about fire risk and fire propagation modeling, end-users are able to utilize a wide range of maps directly in the web browsers of their PC's, portable computers, Global Positioning Systems (GPS) or smartphones; i.e. with no other specialized tools required to be installed in their devices. Thus, with this approach a valuable assistance and a decision tool is offered to the local authorities responsible for wildfire management to extract useful information towards the design of an effective operational wildfire prevention and management plan. All available output results are visualized by utilizing the web-GIS design tools that provide powerful mapping and geo-processing functionalities free-of-charge.

With the AEGIS innovative and advanced programming tools, firefighting personnel, emergency crews and other authorities can design an operational plan to encompass the forest fire. Fire management professionals are able to locate vehicles of the Fire Service and other resources online and in real-time. Fire patrol aircrafts using GPS tracking and communications have the ability to send coordinates for each item to the system, depicting them on an electronic map; and detection cameras could augment these data by transmitting images of high risk areas into the AEGIS fire system. The AEGIS platform enables end-users to query the databases and get answers immediately, locate points of interest in high-resolution satellite images and connect their portable computers or GPS devices to download information.

The AEGIS application is able to offer services beyond simple coordination of emergency activities. Remote automatic weather stations and a weather forecasting system based on the SKIRON/RAMS weather model provides crucial data needed for fire prevention and early warning. Geographical representation of the fire risk potential and identification of high-risk areas at different local regions is being provided daily, based on parallel computer processing techniques; to resourcefully improve the current fire risk estimation methodology used by the Greek General Secretarial for Civil Protection and come up with the first ever quantitative Greek Fire Danger Rating System. By using and testing the innovative proposed fire behavior algorithms, maps are produced on demand and real-time to graphically represent the spread and intensity of a forest fire at different times and places, including burn probabilities and fire effects. All these information are calculated with advanced parallel processing computer techniques, in this proposed state-of-the-art project in terms of human, technical and research resources.

The developed system is applied in seven (7) different study areas with high-hazard, high-value and high-use wildland-urban environments. Each area covers a mix of different conditions either in socioeconomic situations (i.e. rural/ urban and interface areas, changes in population size/ density etc.) or in environmental factors (i.e. weather, vegetation, topography etc.). By applying the results and outcomes of this research in the areas, knowledge is gained and tools are developed that may allow us to apply the system to the rest of Greece with minimal effort and resources in the future.

3. ANALYSIS OF GOALS AND PROCESSES

Initially, the analysis of the organizational goals and the corresponding processes that must be followed is conducted. The purpose of goal-processes analysis is to find the specific objectives that must satisfy the system to be built. The result of this analysis is a UML diagram that conceptually represents the relationships between objectives and processes.

The analysis starts with the most generic goal and concludes in concrete objectives, the implementation of which leads to achieving the overall objectives set out in the more generic levels. Each final target is associated with one or more processes. The processes are those that determine the developing system services and provide a guide for the development team, because the implementation of processes means the achievement of the objectives set.

The mapping of the goals (G) and processes (P) follows the reverse tree format where the highest node is the root of the tree (Figure 1). The analysis using the target-process model is necessary to precede any other analysis, because it provides:

- A clear imprint of the objectives of developing the system.
- A mapping of relationships between objectives.
- An analysis of the objectives in specific ones that contribute to easier and faster implementation of the system.
- The confirmation that all requirements have been taken into consideration.

The diagram in Figure 1 shows the model of the goals and processes revealed by the analysis of the system. The model describes the objectives derived from functional and non-functional requirements. Functional requirements describe the basic needs that must be satisfied by the system and from which all services of the system are derived for each user group. Non-functional requirements describe mainly rules that should be applied to all services of the system and usually are about the safety of users and data, the maintenance of the system's availability and data integrity. In general, non-functional requirements lead to "horizontal" implementation of services for the whole system and not individual services. The processes presented facilitate the easier transition from the theoretical objectives in the implementation of the services offered by the system.

As stated above for completing the goal-process model the following tasks were conducted:

- An analysis of the system needs as being expressed by the description presented in the introduction. The aforementioned description was shaped with the system's stakeholders and the team of analysts.
- Interviews with the major end-users the respective system is intended to be used from.
- Identification of non-functional requirements based on previews experience of the designer team as well as the respective literature described in the introduction.

The result of the analysis is presented in Figure 1. All decomposition links between parent (higher level) and child (lower level) goals are "AND" decomposition links meaning that the realization of the parent goal requires the successful realization of all child goals. The proposed services that will be implemented through the identified processes are matched with the end goals in Table 1.

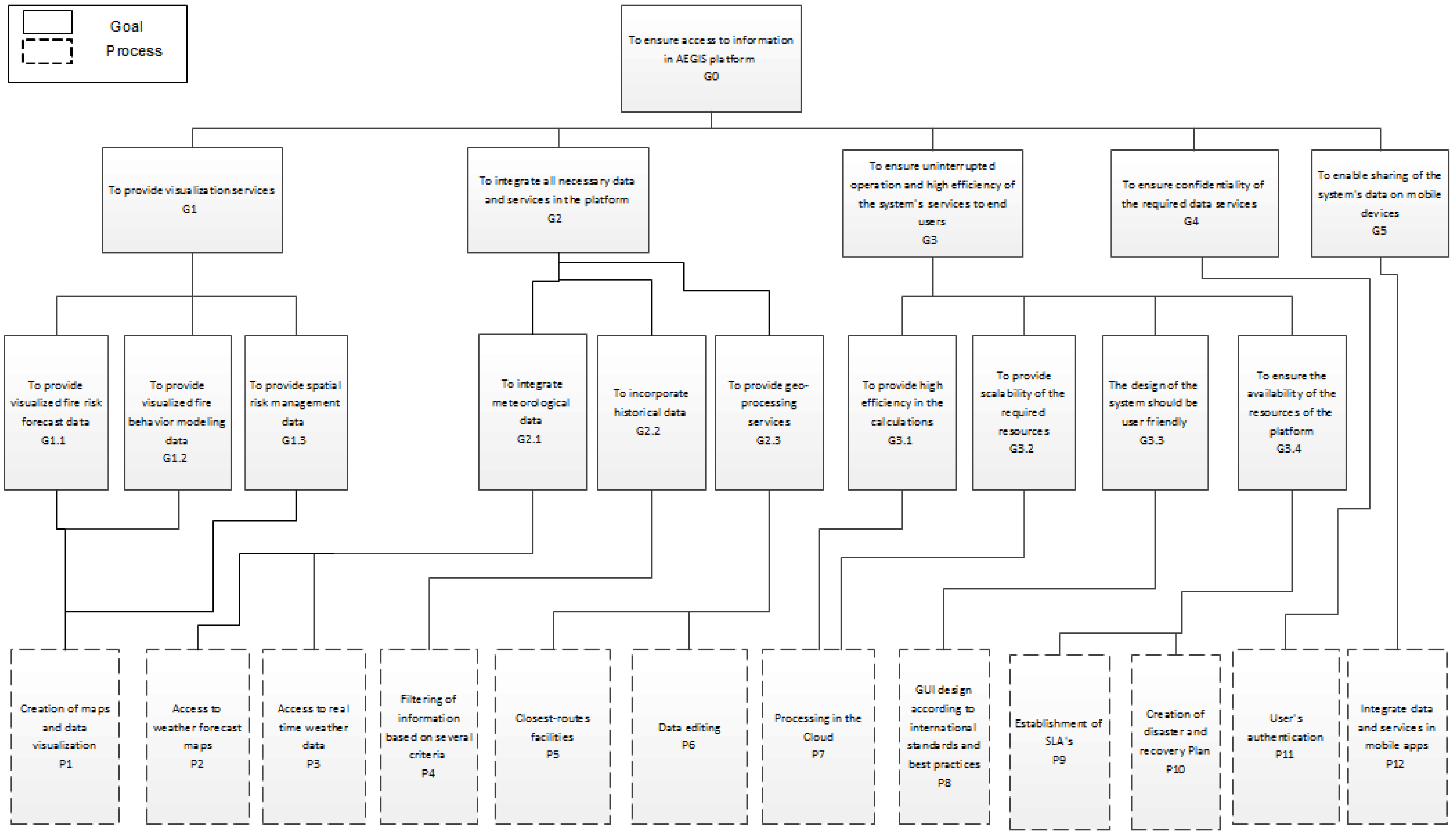

Figure 1 The Goal – Process diagram

Service	**Goal (G)**	**Process (P)**
Visualization of fire risk maps (Vasilakos et al., 2007)	G1.1	P1, P7
Visualization of burn probability maps (Ager et al., 2011)	G1.2	P2, P3, P7
Visualization of real time weather data	G2.1	P3
Visualization of forecast weather data	G2.1	P2, P7
Access to fire management data, i.e.: • Base maps / satellite maps • road network • water sources • evacuation sites • cover types • high risk areas	G1.3	P1
Exploitation of Google Earth (KML) data	G1.3	P6
Online map creation	G2.3	
Map printing	G2.3	
Access to historical fire risk data	G2.2	P4
Access to historical weather data	G2.2	
Access to historical burn probability maps	G2.2	
Routing	G2.3	P5, P11
Finding the closest routes to water sources	G2.3	P5, P11
Calculate drive times from a specific location	G2.3	P5, P11
Location tracking of fire vehicles on duty	G2.3	P6, P11
Visualization of new fire spots	G2.3	P6, P11
Access to web cameras	G2.3	P6, P11
Access to the provided information through mobile apps	G5	P12
Fire behavior simulation	G1.2, G1.3, G2.1, G2.2	P1, P2, P3, P11

Table 1 Analysis of services, goals and processes of the AEGIS platform

4. USER REQUIREMENTS IDENTIFICATION

To confirm the usefulness and necessity of the aforementioned analysis, a questionnaire with the proposed services was compiled. The questionnaire was answered by different groups of potential key users to consider the priorities of the functionalities that will be developed. Questions were either qualitative (e.g. “How important do you consider the calculation of the risk?”) or quantitative (e.g. “*What is the preferred time frame for the creation of the fire risk maps?*”*)*. The full questionnaire is presented in Appendix I. The analysis of the user’s replies to the questionnaire in order:

- To confirm that the proposed services cover the requirements of the potential users of the system.
- To emerge the individual characteristics of the services that will help the developers to better customize these services.

The questionnaire was drawn up with the help of the free, web-based software Google docs and emailed in a large sample of the end users. Particular emphasis was given to the heterogeneity of the sample; i.e. users should have true connection with the subject of the work, but they should come from different organizations. The questionnaire was answered by 34 people who work in research organizations, higher education institutions, fire and forest services, business organizations and firefighting volunteers.

The services offered were grouped into functional and non-functional requirements. Functional requirements describe the proposed operations that should be running by the system. Non-functional requirements include general characteristics of the system. Users were asked to answer how important would be if the system was built according the following characteristics:

- Efficiency; where users were asked about the necessity each of the services to be available in low response time.
- Availability; where users were asked about the necessity each of the services to be available at specific time periods.
- Usability; where users were asked about the necessity each of the services to have an operation guide and assistance for their use.
- Security; where users were asked about the necessity each of the services to be accessible only through credentials.

The analysis of the results from the questionnaire answered by the groups of potential users is shown in Table 2. The specific results assist the designers and developers on building a system that will satisfy the user's needs in a more holistic manner.

Requirement	**Decision**
Preferred time frame for the creation of the fire risk maps	72 hours
Risk maps to be provided by the application within the preferred time frame	1 map / 6 hours
Preferred maximum time duration of fire simulations	12 hours
Preferred time frame of accessing historical fires	1 decade
Fires interested to have access to burned / reforested areas	> 100 ha
Preferred measurement units of wind speed	km/h and Beaufort
Types of base maps that should be incorporated	Satellite images and annotation
Preferable period in which the provided services will be available	Throughout the year for all provided services except of risk assessment and burn probability services that are necessary from May until end of September.

Table 2 User requirements through questionnaire analysis

5. USE CASES

After the analysis of the results from the questionnaire, different use cases of the system are modelled by using UML use case diagrams. These diagrams contribute to the emergence of the services that each group of end users has access. As a consequence, the services can be developed by assigning the appropriate access rights to the corresponding user groups. Three groups of users were identified:

1. Basic user group: In this group belong non-registered users that will be able to utilize only a subset of the services provided. These services include any non-critical functionality; e.g. visualization of any map (except fire behavior simulations maps), accessing real-time weather data and searching for historical weather data.
2. Privileged user group: This group will have access to the full functionality provided; critical functionalities such as accessing maps of fire behavior simulations will be provided only through the corresponding credentials.
3. System's administrators: This group contains the Web Server's administrators as well as the Cloud's platform administrator.

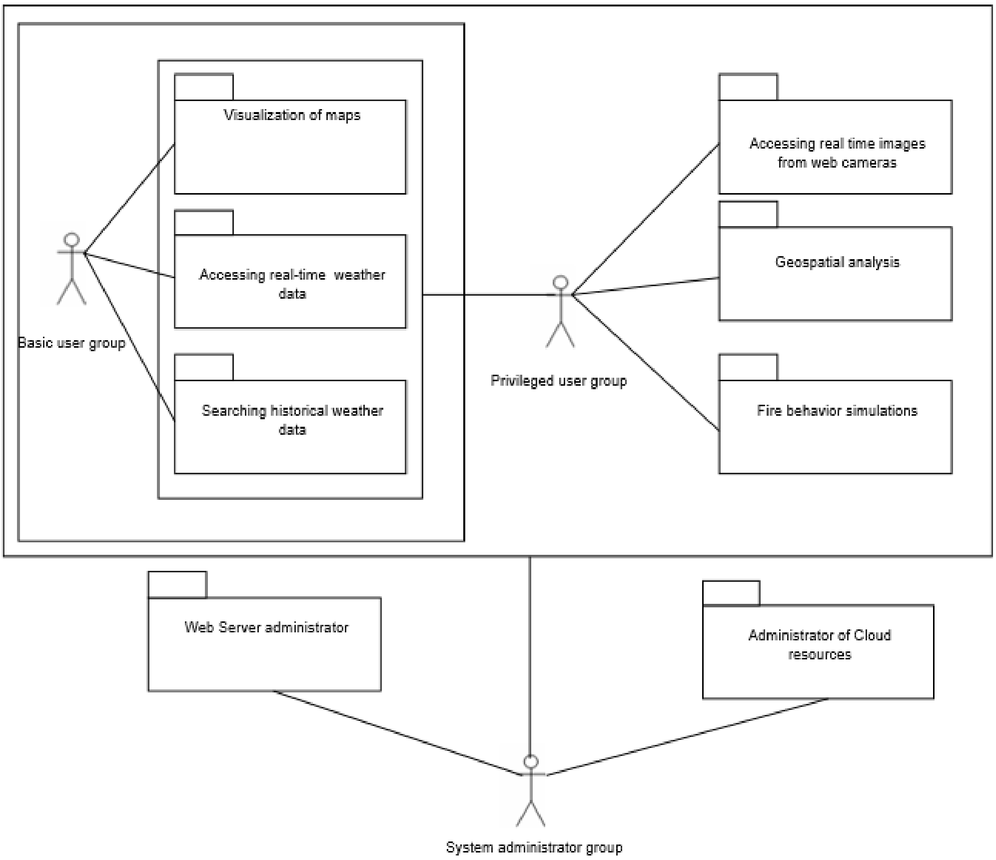

Figure 2 UML diagrams for different use cases

Because of the large number of the services offered, Figure 2 shows only the use cases for each user group. Table 3 lists the detailed services for each use case, as well as the user group that has access for the specific service.

Specifically, the first user group is able to access these kind of data and tools that are not considered private and confidential for fire prevention and management. Thus, the basic group of users is able to visualize fire risk maps, burn probability maps, real time weather data, forecast weather data as well as historical data. However, they are not able to utilize geospatial analysis tools (e.g. routes to the closest water sources) and conduct fire behavior simulations. Only authorized users can exploit these tools. Finally, administrators cannot only use geospatial analysis tools and conduct fire behavior simulations, but they also can manage the web server as well as the allocation of the Cloud resources.

Service	Use cases	User’s group
• Visualization of fire risk maps • Visualization of burn probability maps • Visualization of real time weather data • Visualization of forecast weather data	visualization of maps	*Basic*
Access to fire management data, i.e.: • Base maps / satellite maps • road network • water sources • evacuation sites • cover types • high risk areas	fire management data	
• Exploitation of Google Earth (KML) data • Online map creation • Map printing	mapping tools	
• Access to historical fire risk data • Access to historical weather data • Access to historical burn probability maps	historical data	
• Routing • Finding the closest routes to water sources • Calculate drive times from a specific location • Location tracking of fire vehicles on duty • Visualization of new fire spots	geospatial analysis	*Privileged*
Access to web cameras	Web cameras	
Fire behavior simulation	Web server administration	
Administration	Web server and Cloud administrator	*Administrators*

Table 3 Alignment of the proposed services in corresponding user’s groups

6. ARCHITECTURAL COMPONENTS

Figure 3 shows the software components of the proposed platform. In the front-end layer, end-users will utilize a wide range functionalities directly in the web browsers of their PC's (through the web application) and smartphones (through the corresponding mobile app for Windows Phone devices), with no other need to install any specialized tools in their devices.

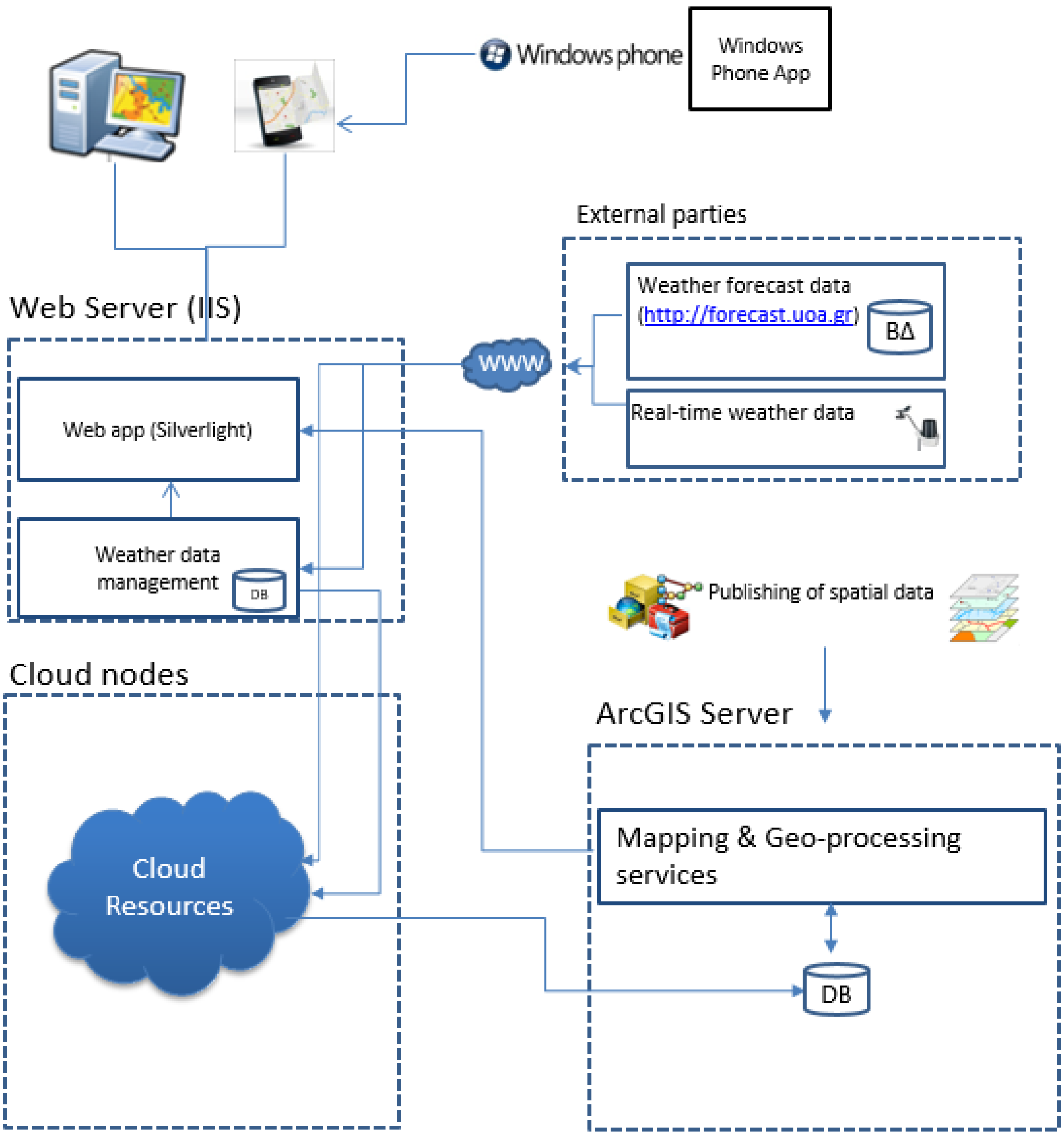

Figure 3 Architectural components of the proposed system

The ESRI ArcGIS API[1] is used for the construction and implementation of the platform's graphical interface, based on the Silverlight framework. The API allows the development of web-based applications that integrate geo-processing and mapping services provided by the geographical server ArcGIS Server. Among the hosting of the Silverlight application, the Web Server (IIS) is responsible for the retrieval of the meteorological data collected from the remote automatic weather stations. Data are collected at the remote stations by special sensors with the help of special software and are sent to the server where they are collected, analyzed and visualized. The values are stored in specific databases so that users have access to weather data from any desired time period. Data from external sources (e.g.

[1] https://developers.arcgis.com/silverlight/

new fire ignitions captured by satellites, images from web cameras and weather forecast data) are collected through the http and ftp protocols.

The ESRI ArcCatalog and ESRI ArcMap software is used for digitization, analysis and management of geographic data. Field data are collected from all the study areas to create spatial and non-spatial databases. Spatial data include road networks, vegetation cover types, fuel types, water sources, topography, dispatching resources, social structures and urban areas, etc. Existing databases, if available, are updated based on these data. In order to create a reliable fire risk and behavior database, we were obligated to undertake field inventories to acquire information about vegetation cover types of the study areas; and then, to create spatial datasets through the use of remote sensing (by acquiring recent satellite images), spatial statistics and GIS techniques. The result are spatial datasets of fuel models, canopy cover, canopy base height, canopy bulk density and stand height; i.e. the necessary inputs for predicting surface and crown fires with fire behavior models. The data are organized into geographic databases and are published in the form of geographic services from the server ArcGIS Server. The geographical services involve viewing static data (cartographic, road network, hydrant locations, evacuation areas, land use, high-risk sites, vegetation types), and services like finding shortest route between points, finding the nearest hydrant seats set point, calculating the extraction region from the designated point at a specified time and digitization fire incidents and hydrant locations.

Furthermore, Cloud-based and HPC-based components are utilized to ensure both power and speed of the calculations. The internal operating mechanisms of the Cloud platform ensure high connectivity and high availability of data and services through appropriate Service Level Agreements (SLAs). This ensure the continuous functionality of the provided services. The available nodes in the Cloud (beyond the visualization of results) undertake the calculation of fire ignition risk maps, the calculation of the burn probabilities maps and the conduction of the fire behavior simulations. To reduce the overall cost of Cloud resources usage, the number of available nodes is increased or decreased, depending on the actual needs. The number of available virtual machines is increased when new forecast weather data are available (i.e. every morning at a predefined time). After scaling up, every virtual machine downloads external data (i.e. real time weather for a specific hour of the next five days data), internal data (i.e. static data stored in the Cloud such as topography, vegetation, fuel types and socioeconomic inputs) and generates the corresponding maps. Execution is conducted in the Cloud by assigning a task to a specific virtual machine (Figure 3). Following job execution, the deployment is automatically scaled down. The results of the calculations are stored in special files BLOBS (Binary Large ObjectS) and are accessible to end users through the graphical interface of the application. Table 4 lists the proposed services and the software component, which participate in the development of the service.

Service	Architectural Component
• Visualization of fire risk maps • Visualization of burn probability maps • Visualization of real time weather data • Visualization of forecast weather data	Web app, Windows Phone app
Access to fire management data, i.e.: • Base maps / satellite maps • road network • water sources • evacuation sites • cover types • high risk areas	ArcGIS Server
• Exploitation of Google Earth (KML) data • Online map creation	Web app

• Map printing	
• Access to historical fire risk data • Access to historical weather data • Access to historical burn probability maps	Web app
• Routing • Finding the closest routes to water sources • Calculate drive times from a specific location • Location tracking of fire vehicles on duty • Visualization of new fire spots	ArcGIS Server
Access to web cameras	External parties
Access to the provided information through mobile apps	Windows Phone app
Fire behavior simulation	Cloud nodes
Administration	ArcGIS Server, Cloud nodes, Web Server

Table 4 Services and corresponding software components.

7. CONCLUSIONS

This article presents the requirements analysis of the wildfire prevention and management platform AEGIS. One of the compelling advantages of the system lies in leveraging GIS capabilities without the need for extensive training on commercial or complicated GIS applications; especially that evidently, operational forces lack the know-how and expertise to develop and operate their own computing and IT systems. With the AEGIS innovative and advanced programming tools, firefighting personnel, emergency crews and other authorities will design an operational plan to encompass the forest fire, pinpointing the best ways to put it out with new levels of precision. Fire management professionals will locate vehicles of the Fire Service and other resources online and in real-time. Fire patrol aircrafts using GPS tracking and communications will send coordinates for each item to the system depicting them on an electronic map; and detection cameras could augment these data by transmitting images of high risk areas into the AEGIS system. The methodology described can be used as a framework in the development of forest fire management systems. Analysis of the requirements is essential, because stakeholders and the team of analysts have different conceptual approaches for the functionalities and capabilities of the system.

The current prototype is applied in 7 different study areas of Greece. Further research plans may include the utilization of the application in different geographical areas and in larger spatial contexts. By applying results and outcomes of this research on the study areas, knowledge is to be gained and tools to be developed that may allow the expansion of the system to the rest of Greece or other areas with minimal effort and resources.

8. ACKNOWLEDGMENTS

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APPENDIX I

QUESTIONNAIRE FILED BY THE END USERS

Functional Requirements	
How important do you consider the calculation of the risk?	◌ not important ◌ quite important ◌ necessary
What is the preferred time frame for the creation of the fire risk maps?	◌ 24 hours ◌ 72 hours ◌ 120 hours
Within the time frame chosen in the previous question, how many risk maps would you like to be provided by the application?	◌ 1 map / hour ◌ 1 map / 6 hours ◌ 1 map / 12 hours ◌ 1 map / 24 hours
How important do you consider the fire behavior simulation?	◌ not important ◌ quite important ◌ necessary
What is the preferred time duration of fire simulations?	◌ Up to 3 hours ◌ Up to 3 hours ◌ Up to 24 hours ◌ Up to 3 days
What is the preferred time frame of historical fires?	◌ 1 decade ◌ 1 decade ◌ 1 decade
For which fires are you interested to have access to burned / reforested areas?	◌ For fires above 10 hectares ◌ For fires above 10 hectares ◌ For fires above 100 hectares ◌ For fires above 1000 hectares
How important do you consider the functionality of accessing historical fires based on the time/date of the fire ignition?	◌ not important ◌ quite important ◌ necessary
How important do you consider the functionality of accessing historical fires based on the size of the burned area?	◌ not important ◌ quite important ◌ necessary

How important do you consider the recording of weather conditions from remote automatic weather stations?	◌ not important ◌ quite important ◌ necessary
Which of the following weather forecast maps do you prefer to be incorporated in the system as?	◌ Maps of wind speed / wind direction ◌ Maps of wind speed / wind direction ◌ Maps of Air temperature ◌ Maps of Relative humidity ◌ Maps of Cloud precipitation ◌ Maps of Fuel moisture 10-h
What are the preferred measurement units of wind speed?	◌ m/s ◌ km/h ◌ Beaufort
How important do you consider the functionality of retrieving historical weather data recorded by the remote automatic weather stations	◌ not important ◌ quite important ◌ necessary
Which of the following fire management data do consider necessary for visualization purposes?	◌ Road network ◌ Water sources ◌ Vegetation and cover types ◌ Evacuation areas ◌ High risk areas (gas stations, houses in urban areas etc.)
Which of the following base maps should be incorporated in the final system?	◌ Satellite images ◌ Satellite images ◌ Aerial photography ◌ Annotation

Which of the following services of fire risk analysis should be incorporated in the final system?	◌ Online Editing ◌ Real – time images from web cameras ◌ KML layers support ◌ Geo-location of fleet tracking ◌ Closest routes to water sources ◌ Drive times from a specific location ◌ Routing
Which of the following services should be incorporated in the mobile app?	◌ Tracking the current location of the user ◌ Closest routes to water sources ◌ Access to real-time weather measurements from the closest weather station ◌ Tracking the current location of the user ◌ Closest routes to water sources ◌ Access to real-time weather measurements from the closest weather station
Non-functional Requirements	
Efficiency: How important do you consider efficiency for the provided services?	◌ not important ◌ quite important ◌ necessary
Availability: Which is the most preferable period in which the provided services will be available?	◌ May-September ◌ October-April
Usability: How important do you consider providing a manual / operation guide for each of the functionalities of the system?	◌ not important ◌ quite important ◌ necessary
Security: How important do you consider accessing services only through credentials (user name & password)?	◌ not important ◌ quite important ◌ necessary