LOCATION DETERMINATION OF AUTOMATIC FOREST FIRE MONITORING STATIONS BASED ON AHP AND GIS DATA

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Abstract

Forest fires represent a constant threat to ecological systems, infrastructure and human lives. Great affords are therefore made to achieve early forest fire detection, which is traditionally based on human surveillance. A rather more advanced approach to human forest fire surveillance is installation of remotely controlled video cameras on monitoring spots. The next, even more advanced step is automatic surveillance and automatic early forest fire detection. In almost every country which encounters high risk of forest fires at least one such systems was developed, proposed and implemented. In Croatia that is iForesFire developed at University of Split.

Croatia belongs to countries with enhanced summer forest fire risk particularly the Dalmatian coast and islands. Because of that a lot of efforts have been made in forest fire prevention. Split and Dalmatia County is the leader in those efforts. Since 2003 University of Split, Split and Dalmatia County authorities and Fire Brigade Administration for the Coast work together on development and establishment of holistic forest fire prevention approach. Its technical part is based on automatic forest fire monitoring network and advanced information system.

One of quite important tasks in development of the forest fire monitoring network is the monitoring stations location determination. This paper describes the approach applied in Split and Dalmatia County. It was based on Analytic Hierarchy Process (AHP) as multi-criteria decision making procedure and intensive use of GIS data. The final result was the network of 56 monitoring location optimally located according to set of various fire-monitoring, technical and economic criteria.

Introduction

Forest fires represent a constant threat to ecological systems, infrastructure and human lives. According to prognoses, forest fires, including fire clearing in tropical rain forest, will halve the world forest stand by the year 2030. In Europe, up to 10,000 km^2 of vegetation are

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destroyed by fire every year, and up to 100,000 km^2 in North America and Russia. Approximately 20% of CO_2 emission into the atmosphere is caused by forest fires (Kührt et al. 2001) .

Croatia belongs to countries with high forest fire risk. In summer seasons seven coastal counties in Croatia and in particular the Adriatic islands are permanently exposed from high to very high fire risks, due to densely-spaced conifer forests. Only in Split and Dalmatian County in the year of 2003, wildfire occurred as many as 130 times. The total burned area in the year 2003 was 9.700 ha. The direct and indirect damage of the lost woody biomass was assessed at the level of 16 and 60 mil.€, respectively (Hrastnik et al. 2004).

The only effective way to minimize damage caused by forest fires is forest fire early detection and fast reaction, apart from preventive measures. Great efforts are therefore made to achieve early forest fire detection, which is traditionally based on **human surveillance**. Usually the human surveillance is realized by 24 hours observation by human observers located on selected monitoring spots. In Croatia the human forest fires surveillance is mainly organized by Croatian Forests (Hrvatske šume) – the governmental organization responsible for protection and exploitation of forests in state ownership. Human surveillance is usually organized only during summer months. For example in Split and Dalmatia County there are 16 forest fire surveillance stations of Croatian Forests in operation from June 1st to September 15th and few other observation stations organized by local authorities and organizations. Human observers are usually equipped only with standard binoculars and communication equipment and their observation area is the area covered by their sight of view. Croatian official regulations define that the maximal distance between two monitoring spots have to be less than 15 km, but in practice that is hardly achieved.

A rather new, technically more advanced approach to human forest fire surveillance is installation of **remotely controlled video cameras** on selected monitoring spots. Now the human observer is not anymore located on the monitoring spot. His observation station is the monitoring centre equipped with adequate video presentation and video storing devices, wires or wireless connected with distant video cameras located on monitoring spots. The video cameras based human forest fires surveillance has many advantages in comparison to direct human observation on monitoring spots. Let us mention the most important of them:

a) Using video cameras the human observer is capable of monitoring a wider area covered by few video monitoring field units.

b) Cameras are usually equipped with power zoom (optical zoom with at least 20 x magnification) so the observer could easily inspect suspected areas.

c) Such system usually has video storing capabilities, at least for the last couple of days, so stored video data could be quite useful in post-fire analysis.

d) The application of video monitoring stations is not limited only for forest fire prevention tasks. They could be successfully used during fire fighting as distant video presets device.

The next more advanced step in forest fire monitoring is **automatic surveillance and automatic early forest fire detection system**. The research and system development in this area was extended in the last couple of years. There are two main types of automatic forest fire surveillance:

a) terrestrial systems based on monitoring from ground monitoring stations, and

b) satellite systems based on monitoring from satellites.

Satellite systems are suitable for monitoring wide forest areas like Canada or Siberia Sometimes airplane-based systems are used to monitor such areas, but today wide area monitoring is usually only satellite-based. As an example, let us mention Canadian Fire

Monitoring, Mapping, and Modelling (Fire M3) System (Fire M3, 2007), or European FUEGO program (Escoral et al, 2001).

For monitoring areas like the Adriatic coast and islands the satellite monitoring is not appropriate solution. Terrestrial or ground-based systems are much more suitable. In terrestrial systems different kinds of fire detection sensors could be used like:

a) video cameras sensitive in visible spectra – forest fire detection is based on smoke recognition during the day and fire flame recognition during the night,

b) infrared (IR) thermal imaging cameras – forest fire based on detection of heat flux from the fire,

c) IR spectrometers – forest fire detection is based on identification of the spectral characteristics of smoke gases, and

d) light detection and ranging (LIDAR) systems - forest fire detection is based on measuring of laser light backscattered by the smoke particles.

Infrared and laser-based systems are more sensitive and they generate less false alarms, but their price is quite height in comparison to video (CCD) cameras sensitive in visible spectra. For example the price of one typical high quality outdoor pan/tilt CCD camera is 3.000 €, and the price of one typical IR thermal imaging camera is 25.000 €., 8 times more. Additional feature of CCD video cameras which are today on the market is their dual sensitivity. They are color cameras sensitive in visible spectra during the day, and black and white cameras sensitive in near IR spectra during the night.

Figure 1. *Croatian* ***iForestFire*** *monitoring station in experimental work on Marjan hill (Split area) during 2005 and 2006 fire season*

The terrestrial systems based on CCD video cameras sensitive in visible and near IR spectra are today the best and the most effective solution for realizing automatic surveillance and automatic forest fire detection systems. In almost every country which encounters high risk of forest fires at least one such systems was developed and proposed. Some of them are on the market under various commercial names like FireWatch (Germany), FireHawk (South Africa), ForestWatch (Canada), FireVu (England), UraFire (France). In Croatia one such system named **iForestFire** (Stipanicev et al, 2006) (iForestFire, 2007) was developed at University of Split. In all those systems automatic forest fire detection is based on smoke recognition during the day and flame recognition during the night. **Fig.1** shows iForestFire monitoring station during 2005 and 2006 experimental work on Marjan hill in Split area.

Implementation of one forest automatic fire monitoring station is better then no one, but for efficient forest fire monitoring a **network of monitoring stations** have to established. Planning of automatic monitoring stations locations is quite sensitive task because a lot of criteria have to be fulfilled and that is the main topic of this paper.

System approach to location determination of forest fire monitoring stations and determination of priority plans for their realisation

Locations of automatic forest fire monitoring stations could not be arbitrary defined. A lot of different fire-monitoring, technical and economic criteria have to be satisfied. On one side the ideal situation could be to cover all regions with high forest fire degree at least with two monitoring station, but on the other side is reality, particularly the economic reality. Because of that usually the main goal is to maximally satisfy various fire-monitoring criteria with minimal number of monitoring stations and minimal implementation cost.

The first effort to define and optimise the network of forest fire monitoring stations in Split and Dalmatia County appeared in the year 2000. A group of researchers from University of Split Civil Engineering Faculty, Croatian Telecom and UNEP (Mladineo, 2000), (Mladineo and Knezić, 2000) published a pilot study about fire decision support system and suggest the methodology for "optimisation of forest fire sensor network''. Proposed forest fire sensors were monitoring stations equipped with IR cameras having 12 km protecting radius. Their case study was island Brac and PROMETHEE method was used as multi-criteria analysis method based on 6 criteria:

C1 – Land use (urban areas, individual residences, industrial areas, agriculture, woods, maquis)

C2 – Areas around electricity supply high voltage infrastructure (300 m wide)

C3 – Areas around fiber-optic cables (150 m width)

C4 – Protected areas (nature parks)

C5 – Risk areas (waste disposal sites)

C6 – Types of woods (Pinus halepensis, Pinus nigra, Quercus ilex)

Their experiences were valuable for us, but we have further improved the procedure for location selection. The main differences between their approach and our approach were in following items:

a) Monitoring stations in our system are based on networked video cameras sensitive in visible and near IR spectra, connected in IP based VPN (Virtual Private Network).
b) Location selection was divided in two levels
    - determination of all monitoring stations location,
    - determination of priority plans for monitoring station realisation.
c) Another set of criteria was defined, more suitable from fire-monitoring, economic and technical point of view. At each level different criteria were defined.
d) Another type of multiple criteria decision analysis (MCDA) was used, namely the AHP - Analytic Hierarchy Process.

Our final result was the network of 56 forest fire monitoring stations covering all parts of Split and Dalmatia County interesting from the forest fire point of view. Monitoring stations were divided in 10 operative zones and realization was planned in three realization phases. In this paper we will present the first part – location determination using AHP and GIS data.

Location determination of forest fire monitoring stations

Location determination of forest fire monitoring stations is a procedure divided in 5 steps:

a) Criteria definition
b) Determination of all possible locations
c) Evaluation of each location according to defined criteria,
d) Calculation of overall criteria satisfaction degree and
e) Determination of locations list according to overall criteria satisfaction.

Steps c), d) and e) were performed using Analytic Hierarchy Process (AHP) as multi-criteria decision analysis procedure.

Criteria definition

Criteria were divided in two groups: fire – monitoring criteria and techno – economic criteria:

A. Fire – monitoring criteria

A1 Location importance from the fire monitoring point of view

A2 Forest fire danger rating for area covered by monitoring station

A3 Recent and planed protected areas (national parks, nature parks, protected landscapes)

A4 High voltage infrastructure in area covered by monitoring station

A5 Railway in area covered by monitoring station

A6 Risk areas in area covered by monitoring station (waste disposal, places with increase human concentration like sightseeing spots, rest stations and similar)

B Technical and economic criteria

B1 Coverage - percentage of visible area in comparison with maximal potential view area.

B2 Location importance according to other correlated reasons (in area covered by monitoring station there are other important objects like water supplies, waste storage, entrance roads to forest areas etc.)

B3 Not overlapping with another location view area.

B4 Existence of suitable tower where monitoring camera could be mounted like mobile operator towers, TV towers or monitoring towers.

B5 Existence of access road.

B6 Existence of low voltage power supply.

Additionally to those criteria monitoring network communication infrastructure includes some restrictions, too. The communication between stations was planned on maximal use of license free WiFi communication in microwave 2.4 GHz frequency range, and because of that

- monitoring stations have to in each other sight of view and
- distance between monitoring station has to be less than 10 km if we want to be inside EU limits for maximal Effective Isotropic Radiated Power allowed for WiFi communication.

Multi-criteria decision analysis

Multi – criteria decision analysis (MCDA) defined methods and procedures by which multiple and even conflicting criteria could be included in decision process. In our case we have few candidates and few different criteria, and our goal is to find the list of candidates according to their overall criteria satisfaction. There are lot MCDA methods like PROMETHEE (Brans and Vinche, 1985), ELECTRE (Roy, 1991), MAUT (Keeney and Raiffa,1976) or AHP (Saaty, 1980). We have decided to apply AHP because we had previous successful experiences with this method (Mandic et al, 1989), the method is quite simple for use by non-technical people and it has been applied in numerous GIS based decision making situations (Chulmin, 2000).

Analytical Hierarchy process (AHP) is a quantitative method for ranking decision alternatives by developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria. The process involves

1) Identifying the decision elements (selection criteria).

2) Recording relative importance of those elements by pairwise comparison.

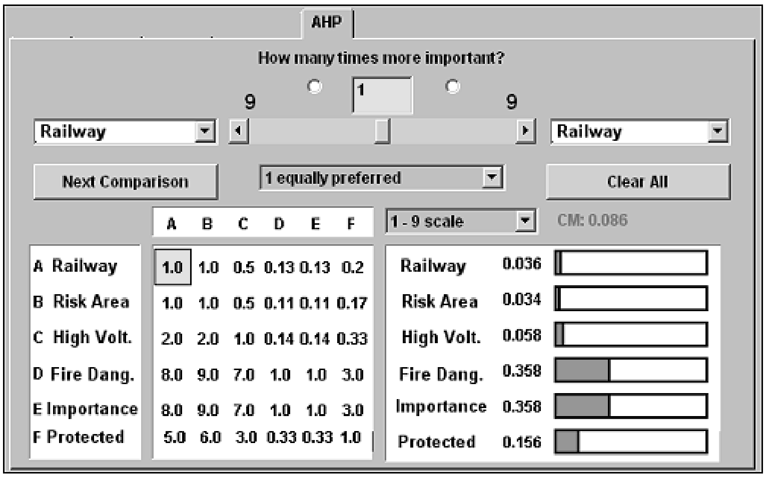
3) Construction of an importance table also by pairwise comparison of alternatives according to each criterion.

4) Final calculation by a simple linear algebra mathematical procedure.

A scale from 1= ''equally important'' through 9 = ''extremely important'' is used to record the relative level of importance for the pairwise combinations of the decision elements. Reciprocal values means opposite level of importance for example 1/9 = ''extremely non important''.

In our case we had two groups of criteria: fire –monitoring and technical-economic and we suppose that each of them is equally important. Pairwise comparison was performed in each group using Web – HIPRE, a Java based multi-criteria decision support engine develop in System Analysis Laboratory at Helsinki University of Technology (Web-HIPRE, 2007). **Fig.2** shows the comparison table for fire - monitoring criteria.

Figure 2. *Pairwise comparison table of fire - monitoring criteria*



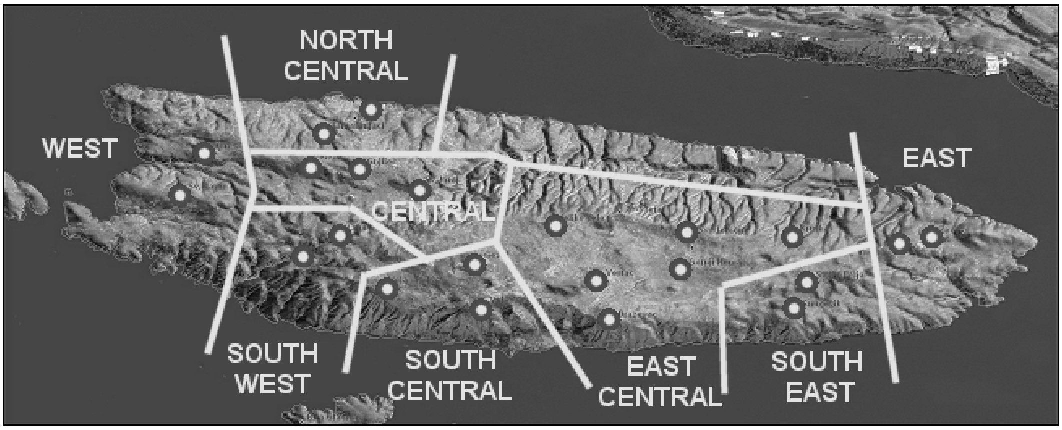
The table also shows the relative importance of criteria obtained as a result of pairwise comparison. Two criteria were on top A1 – ‘’ Location importance’’ and A2 – ‘’Forest fire danger rating’’, both of them having relative degree 0.358. Similar table was calculated for techno – economic criteria. In this group the most important one was B1 – ‘’ Percentage of visible area in comparison with maximal view area’’ with relative degree 0.457.

In the next step all possible locations in one sub-area were compared in pairs according to each criterion using GIS and non GIS data. As a illustrative case study let us show the procedure for island Brac.

Case study: island Brac

Island Brac has specific geographical characteristics and during the summer time the number of tourist three times overcomes the inhabitants (approx. 40.000 tourists and 14.000 inhabitants). Because of its specific mountain relief island Brac was divided in 8 different sub-areas or zones (East, South East, East Central, South Central, Central, North Central, South West and West). North part of island Brac was monitored from the coast. In each zone at least two potential monitoring spots were defined, all together 22 potential monitoring locations. **Fig. 3**. shows all of them.

Figure 3.*All potential monitoring locations on island Brac*



Monitoring stations in each sub-area are pairwise compared according to all criteria, and the winner was chosen as the most appropriate location for that zone. **Fig 4**. shows the comparison results for sub-area East Cetral where three potential locations were defined: Vidova Gora, Gezul and Vela visoka. Vidova gora was the best choice having overall criteria satisfaction degree 0.515. Vela visoka was second with degree 0.265 and Gezul last with degree 0.220.

Pairwise comparison was based on intensive use of GIS data and GIS analysis. For example **Fig.5**. shows two potential locations in East Central zone – Vidova gora and Vela visoka, their field of view and its overlapping with recent and planned protected areas, and its overlapping with high voltage infrastructure. For those criteria (A3 and A4) GIS analysis gave us numerical data for each potential monitoring location. For some other criteria like A1, where it was not possible to use numerical analysis pairwise comparison was made using expert judgment.

The final result was the network of 56 forest fire monitoring stations divided in 10 operative zones shown on **Fig.6**.

Each operation center would be primarily responsible for monitoring stations located in their area, but all of them are also connected together in VPN (Virtual Private Network), so anyone with appropriate authentification can use monitoring stations located in surrounding zones, too. Typical example is island Brac shown in **Fig. 3**. The north island part is better covered by monitoring stations located on the coast in Omis – Makarska area, so the operator on island Brac would be allowed to use monitoring stations on the coast.

Figure 4. *Final result of location selection using AHP applied for zone South Central of Brac*

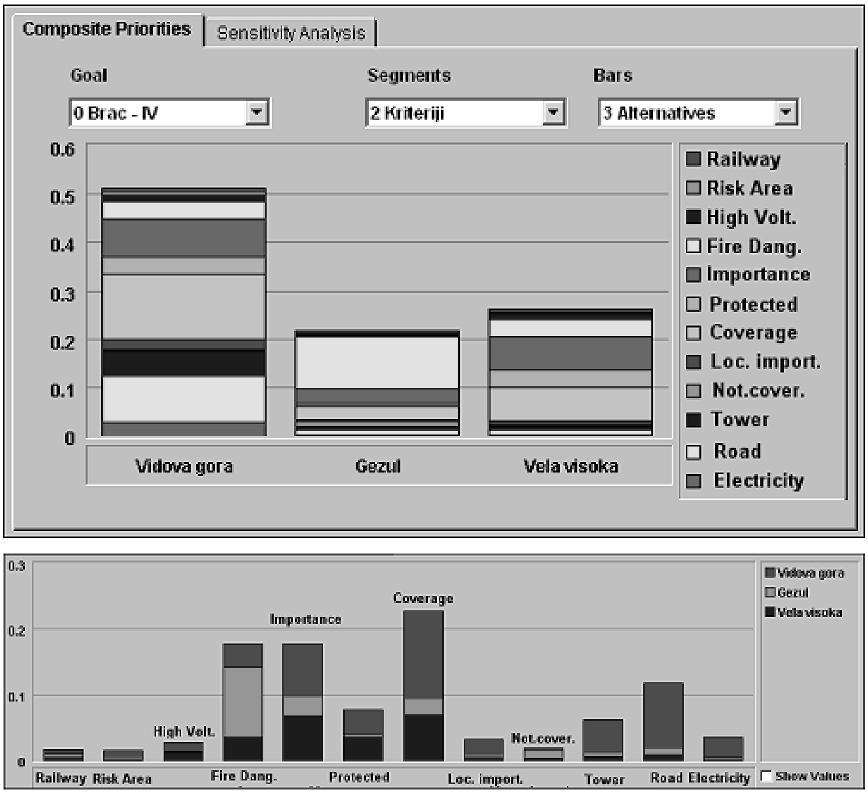


Figure 5.*GIS data used in location selection for zone South Central of island Brac*
1st row - Overlapping of two location field of view and protected areas
2nd row - Overlapping of two location field of view and high voltage infrastructure

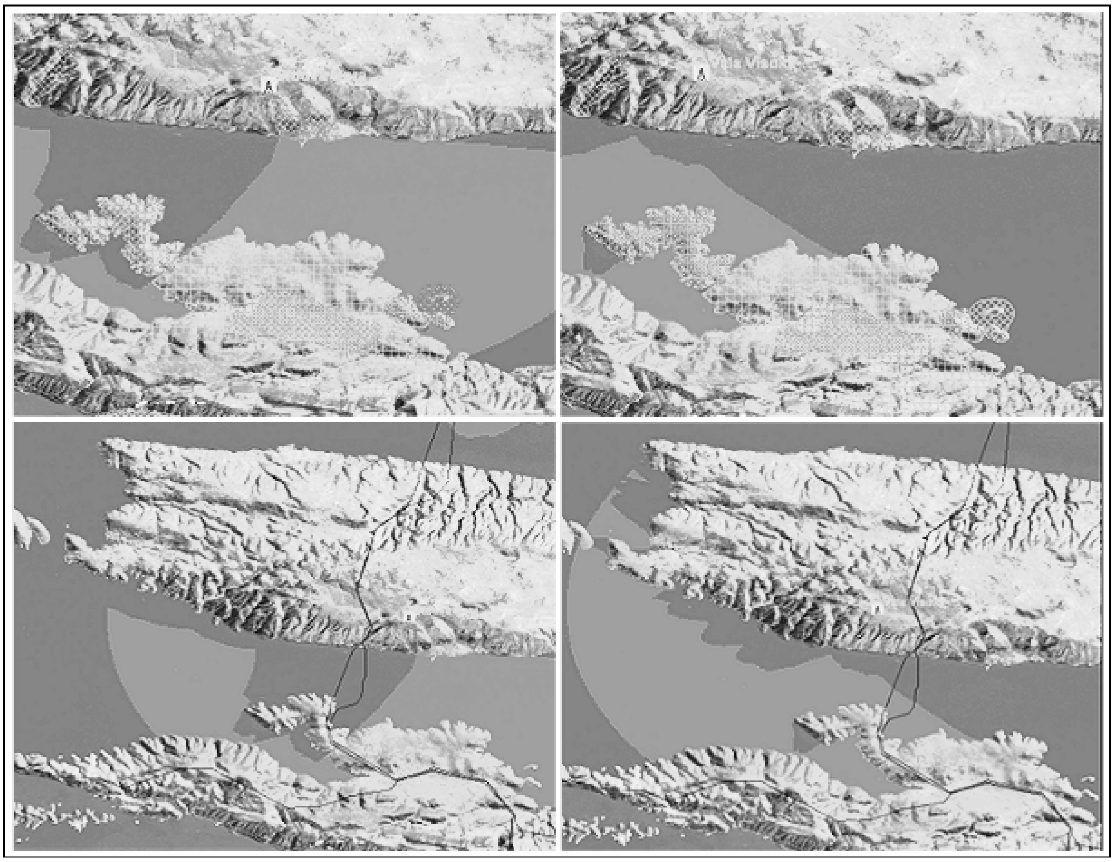
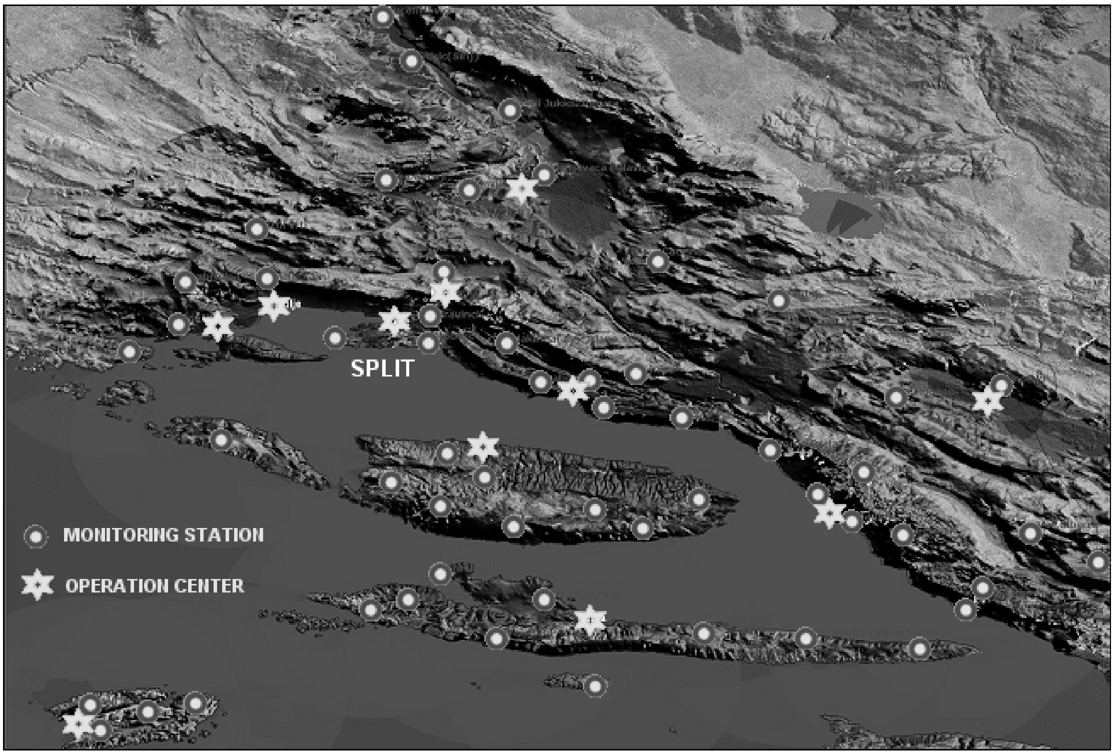


Figure 6. *Split and Dalmatia County future forest fire monitoring network with 56 monitoring stations divided in 10 operating zones*



Similar procedure, also based on AHP and another set of criteria was used in determination of priority plans for monitoring network realization. Three realization phases were defined, each of them having partial operability, but that will be the topic of our next paper.

Conclusion

Today the best cost effective solution for early forest fire detection is automatic forest fire ground based monitoring using cameras in visible spectra. One monitoring station is better then no one, but for efficient forest fire monitoring a **network of monitoring stations** have to established. Planning of automatic monitoring stations locations is quite sensitive task because a lot of criteria have to be fulfilled. Therefore the system approach based on multi-criteria decision analysis and intensive use of GIS data and GIS analyses has to be established. Based on our experiences with experimental tests of Croatian intelligent fire monitoring system – **iForestFire**, we have designed the forest fire monitoring network of Split and Dalmatia County conceived of 56 monitoring stations divided in 10 operating zones. The realisation is planned it three phases and we expect it in the next couple of years.

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Author Biography

Darko Stipanicev is a professor of computer science and electrical engineering, head of Department for modelling and intelligent systems at Fac. of El.Eng., Mech. Eng. and Naval Arch. University of Split. His research interest is complex system modelling and application of intelligent technologies, particularly advanced digital image analysis. Since 2002 he leads a number of research projects connected with forest fires, especially early forest fire detection using video monitoring and development of forest fire integral information system.

Tomislav Vuko is a deputy fire commanding officer responsible for Adriatic coast and islands. His experiences in forest fire fighting were irreplaceable for definition of forest fire monitoring criteria and determination of potential forest fire monitoring locations. He was the main adviser in all our forest fire research and development projects.

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