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ORIGINAL PAPER

An INSPIRE-compliant open-source GIS for fire-fighting management

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Abstract Every year, there are almost 50,000 forest fires in Europe (127/day), which have burned an area equal to more than 450,000 ha. An effective management of forest fires is therefore fundamental in order to reduce the number of the fires and, especially, the related burned areas, preserving the environment and saving human lives. However, some problems still exist in the structure of information and in the harmonization of data and fire management procedures among different European countries. Pursuing the same interoperability aims, the European Union has invested in the development of the INSPIRE Directive (Infrastructure for Spatial Information in Europe) to support environmental policies. Furthermore, the EU (European Union) is currently working on developing *ad hoc* infrastructures for the safe management of forests and fires. Moving from this premises and following an analysis of the state of the art of information systems for forest fire-fighting, in the light of the end-user requirements, the paper presents the INSPIRE—compliant design of a geographical information system, implemented using open-source platforms.

Keywords Forest fire-fighting · Decision support system · Emergency management · INSPIRE data model · GIS

1 Introduction

As a consequence of the global climate change and the interaction among several natural and technological hazards, the number of natural disasters, including forest fires, is increasing. They usually cause life losses and property and environmental damages (IPCC 2014). A recently published international document, the *Sendai Framework for Disaster Risk Reduction* 2015–2030 (Sendai Framework 2015), identifies, considering the open

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problems, two critical issues: the standardization of the risk and danger factors information and the necessity to optimize the employed capital in emergencies.

In the list of main natural and man-made disasters, the forest fires take up an important role, for the seriousness of damages, and the consequent costs (Guha-Sapir et al. 2015). This phenomenon is widely spread in Europe. The total European burned area only in the year 2012 (most recent available official data) is 519,424 ha (European Commission—Joint Research Centre 2012).

In order to be more effective, forest fires require both active and passive fighting activity. In particular, the management of fire emergencies is organized in three steps (Fig. 1).

Management, monitoring of fire risk areas and fire-fighting actions are very complex operations, especially when dealing with "mega fires" (Pyne 2007). Some critical issues have to be solved for effectively perform these activities by means of automatic and integrated tools (Chuvieco and Salas 1996).

During each step, the operators must collect and analyse a lot of data, having various nature (dynamic data, historic series, geometric or thematic data, and so on) (Chuvieco et al. 2010). Private and public institutions produce and provide data in different and, sometimes, proprietary formats (Zlatanova et al. 2010). This produces difficulties in the information retrieval process, and the rapid and efficient interpretation and usage of the data. It is therefore necessary to harmonize the involved data. For example, the national (or even sub-national) digital maps are often structured following local specifications and are shared through independent procedures, which vary in each case.

Finally, the coordination and collaboration among the various operators taking part in the emergency intervention are essential: official forces (land, marine and air), volunteer corps, resources coming from neighbouring countries, providing help, and so on. However, a current difficulty is the coordination process, because it is ruled by different procedures in each country.

These issues have to be taken into action for effectively realizing a unified European supporting system for fire-fighting, possibly sharing and optimizing resources.

The foremost tasks to be realized are as follows: an early warning system and a support for a risk management integrated approach, which allow controlling all the fire-fighting steps (Fig. 1).

Considering these aspects, this study proposes a method to design and implement a standard-based Geographic Information System (GIS) increasing the interoperability of involved data, and producing an effective information for fire-fighting, allowing the possibility of an automatic and real-time data validation and integration. A possible good solution could be the use of the European Directive INSPIRE (Information for spatial information in Europe) (INSPIRE Directive 2007), which has the aim of transboundary

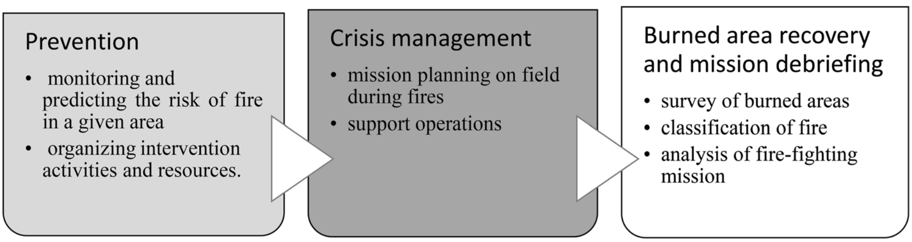

Fig. 1 Steps of the fire-fighting operations

cartographic data harmonization and management for environmental protection and common policies. Nevertheless, the data model proposed by INSPIRE is a complete and international standard-compliant (e.g. with the ISO/TC211 standards) model, suitable to represent cartographic entities even outside Europe. For its completeness and application independence, it could be considered as an ontology.

In the implementation of the system, open-source software products were preferred, because, firstly, they are recommended by programs such as "Interoperable Delivery of European eGovernment Services to public Administrations, Business and Citizens", at European level (European Commission 2004) or Digital Administration Code in Italy. Secondly, open-source software were selected for their well-known features such as cheapness, portability and customization potentiality.

Finally, a further contribution of this study is the introduction of automated processes such as triggers and specific queries, which allow the system to be quickly consulted also exploiting real-time data. Moreover, through similar processes, the system can fill-in automatically, and in real time, some tables useful for the management of the resources in fire-fighting activity (e.g. firefighters teams during emergencies).

2 The state of the art: GISs dealing with fires

Currently, in Europe, there are already several GIS platforms providing decision support for fires issues. However, each system emphasizes only some specific functionality for the stages of the fire management. In recent years, some examples of tailored forest fire decision support systems based on GIS technology have been developed and used in different regions, for example, France, Italy, Spain and the Alpine areas of Europe. However, they do not implement the whole process, but only a part, or some parts of it.

In particular, GIS EMERCARTO (made by TRAGSA) (http://visores.tragsatec.es/) is focused in the command and control of operations, as well as in the management and allocation of fire-fighting resources and support in the decision-making process in real time. Another GIS tool was developed by (Moreno et al. 2012), in which a dedicated simulation was realized for a rapid organization of human resources and their equipment. The capabilities of this tool allow the analysis of the impact of different fire-fighting strategies considering different simulated scenarios of active operations on the field. In Italy, the system called SIRIO was developed by (Losso et al. 2012). This system was tested in Sanremo (Imperia Province, Italy) for monitoring the fire risk areas and giving an early warning message (e-mail or text message) in real time, when the algorithms detect a high risk of fire. Nowadays, the European Forest Fire Information System (European Commission JRC 2000), INSPIRE-compliant, is one of the few GIS applications, aiming at the retrieval of the data from the whole process of fire-fighting. EFFIS GIS acquires, at this moment, only the data (e.g. Risk index, hotspots and size of fire) involved in the fire risk forecasting, and the fires occurred in Europe, using and integrating these historic data to support decisions. Another case of a fully integrated and interoperable system for fire-fighting management is the result of ArcFUEL™ project (Bonazountas et al. 2012), which adopts Global Technology standards at all operational layers (e.g. INSPIRE, OGC and XML/GML). The aim would be providing and producing updated fuel maps to be used in forest fire management operations and geoplatforms as ArcFIRE™ (Mitsopoulos et al. 2014). However, despite these attempts, the use of standards is not so widespread: data content and format are often not uniform, consistent, complete and compatible with the available technologies.

Following a careful analysis of the existing tools, it is possible to notice that an integrated central system is missing. Moreover, it should be underlined that the metadata of the observed maps are almost never available, and it is impossible to determine the quality, accuracy, last updating and further useful information about the data.

3 The design of a standard-compliant spatial data model for fire-fighting

The well-known rules for database modelling, as defined by the ANSI/X3/SPARC standard (Laurini and Thompson 1992), were followed for designing the GIS.

An effective GIS has to consider all the phases of fire-fighting: prevention, preparedness, fire response and recovery (Fig. 2; Neal 1997).

For fire prevention and preparedness aims, GIS should be used for risk analysis and for supporting preventive activities and decisions. Considering these aspects, it is important to integrate various data (e.g. past fires, fuel models and weather) and to simulate some scenarios (Pausas and Fernández-Muñoz 2012) also useful for forecasting activities (Vivalda et al. 2017a).

During emergencies, the GIS should be able to help in real-time mission planning, activities management for fire-fighting, and rescue operations. Being designed as a decision support system, it should also collect and provide information about network infrastructure, buildings, number of people in danger, available water supplies and further useful data involved in the analysis.

For the recovery phase, the system is a useful platform, where to store data of the mission and update the fire registry. These functionalities are very important for fire damage assessment and reconstruction planning.

The GIS proposed is composed of three main categories of objects: the competent authorities and actors in the fire-fighting process (command); the land, intended as objects that are both to be protected and to be considered in the fire-fighting operations, for various

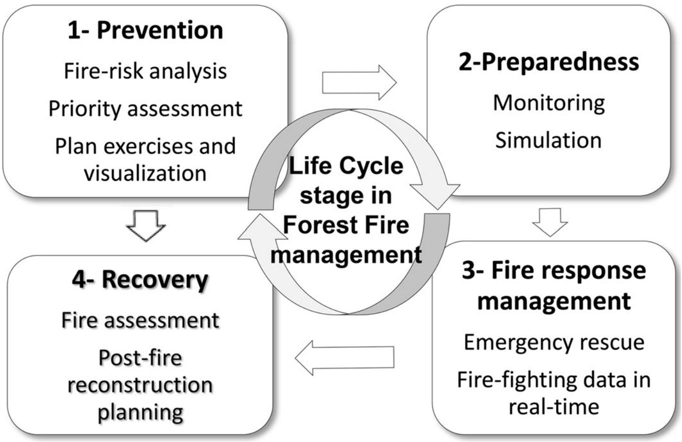

Fig. 2 Schema of the life cycle stages in forest fire management

reasons (infrastructures where to move, water supply resources and so on); and a more dynamic component describing the events (fire and hotspot) (Fig. 3).

The command entities are represented following the proposal of the project of having a unique control centre (the command centre), which coordinates the human resources and the performing operations. This would be a simplification of the actual state of things, since the fire-fighting at present involves, for example in Italy, public and private authorities with the hierarchical order in Fig. 4. Therefore, the proposal of a single command centre for the coordination of activities and data processing is needed to optimize the management, the data distribution, updating and use in emergency situations.

The command centre handles all the data from the local operations centres and is able to direct both the teams moving in the air and the ones acting on the ground. The proposed structure consists in a national unified command centre, that manages the forest monitoring, the fire emergencies and all the equipment for fire-fighting. It coordinates local operating centres, which are responsible for the local resources management, and the updating of the fires registry and the mission report. Finally, the operating teams handle fire-fighting operations in the field (Fig. 5).

The INSPIRE data model provides fundamentals for completely defining the information layers closely related to the land description (e.g. cadastral parcels, building, exposed element and spot elevation), the event development (for instance, event registry and event time) and the meteorological data (e.g. meteorological data and stations) (Burgan et al. 1998; Han et al. 1992).

As previously mentioned, in Europe, a systematic fire model is missing, therefore an approximation on the fuel models was realized, to improve our capacity of fire forecasting and, consequentially, of fire-fighting management. It introduces some vegetation parameters (relative moisture, time lag and combustion heat) that are essential for modelling the forest fire behaviour (Ager et al. 2011).

In the model, both static and dynamic entities, which are collected and produced during the event (e.g. operating team locator or resources available), are included. These latter entities allow the real-time data to be handled and the information to be uninterruptedly updated. The tables are updated in the system through an SQL script, simulating the data

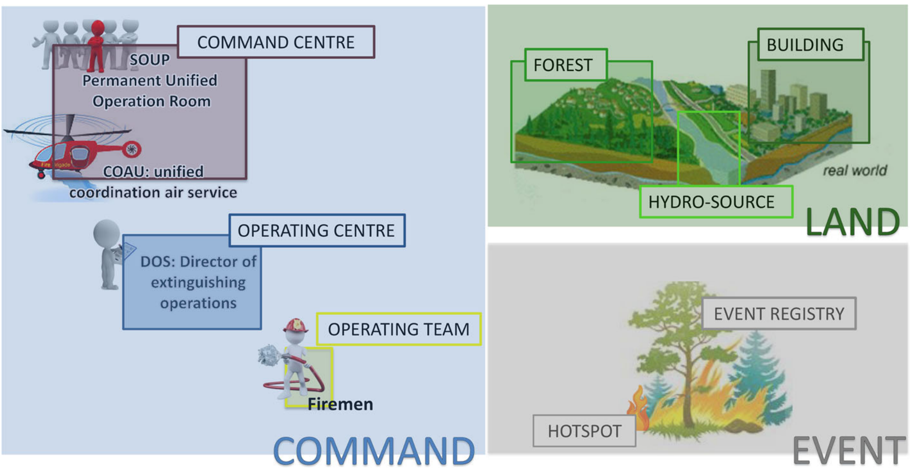

Fig. 3 The three objects categories for the external model development

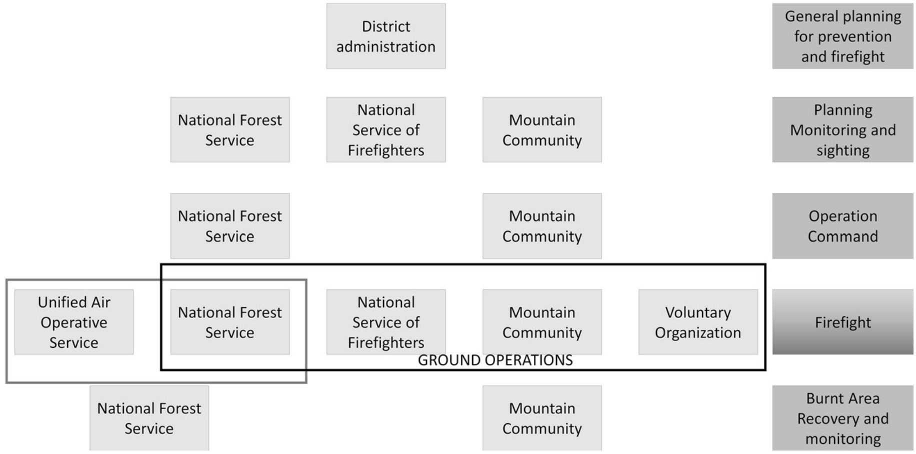

Fig. 4 Involved subject in fire event stages

provided by external data sources. A considered option for a real-time acquisition and communication of the data could be the use of JSON files and protocols provided by the external sources and employed sensors (Sriparasa 2013).

4 The standard data model extension and automatic schema generation: the Model Driven Architecture (MDA) approach

To respond to requirements of interoperability and demands of integration among existing systems and the developed system, the Model Driven Architecture (MDA) approach was developed by OMG (Object Management Group) in 2001. MDA is enabled to development through existing specification such as UML and XMI (Cephas Consulting Corp 2006).

Indeed, the Model Driven Architecture (MDA) approach allows the automatic transformation from an UML diagram to a conceptual data schema script (Lisboa-Filho et al. 2013). More specifically, it allows to translate an object-oriented UML model (Platform Independent Model, PIM) into an object-relational database model in PostgreSQL/PostGIS (Platform Specific Model, PSM).

Enterprise Architect (hereafter EA) by Sparx Systems is the Computer Aided Software Engineering (CASE) tool used to support the GeoDB implementation by means of this approach. This software product is able to automate the construction of a suitable UML (Unified Modelling Language) diagram, permitting the reuse and extension of the already available schemas, to effectively design the database and exchange it through applications.

Thus, to generate an INSPIRE-compliant UML class diagram with interoperable data formats, the INSPIRE UML profile and the INSPIRE repository are imported in EA. The INSPIRE UML profile is an XML file containing the definition of each element present in the UML diagram, essential to interpret its meaning by humans or machines (Kutzner and Donaubauer 2012).

Using the INSPIRE Repository, INSPIRE classes (e.g. Metereological Data, Event-Time, CadastralParcels, etc.), highlighted in the conceptual model (Fig. 5), were extracted and imported into a new model. In order to extend the standard with some tailored features for fire-fighting management, the procedure stated by the OGC as the best practice for

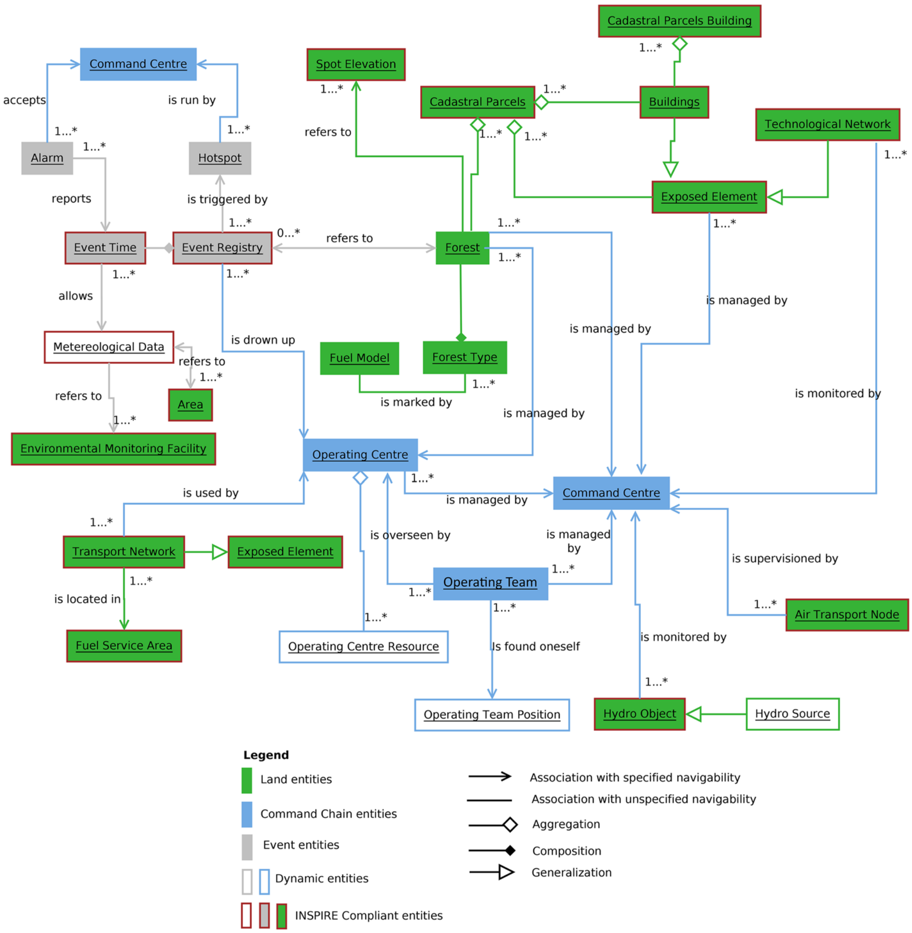

Fig. 5 UML conceptual model including the INSPIRE-compliant entities and their extension for fire-fighting applications

extending the Open Geospatial Consortium (OGC) data model CityGML was used (Van den Brink et al. 2012).

The physical structure of the DB was realized in a semi-automatic way, according to the steps shown in Fig. 6.

The UML Class Model was converted in an XSD (XML Schema Definition) file through the specific Enterprise Architect tool. It is suitable for being used as GML application schema. Then, the XSD was imported and validated with Altova XMLSpy software (or

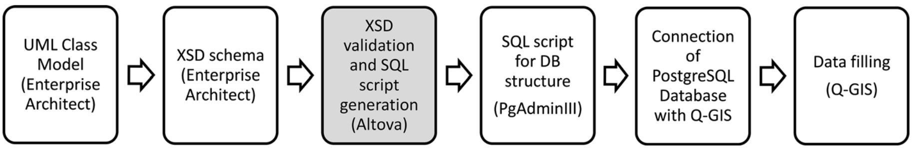

Fig. 6 Procedure of implementation. The underlined passage (in grey) is the only manual step

equivalent open-source ones, such as XPad). During the validation process, the main problem was the recognition of some data types. Indeed, the semantics, in XML format, are different from INSPIRE. For example, the notation of text data type in XML schema is xs:string, while in INSPIRE application schema, the same data type is defined by CharacterString. The only solution, in this case, was the manual editing.

Besides validating the XML application schema, which structures XML data, a tool, integrated in the Altova XMLSpy software, converts the XML schema in an SQL script with a set of Data Definition Langauge (DDL) commands. This is a mandatory procedure in order to generate a relational model-compliant DB in a common SQL-based DBMS software.

The XML editor (in this case, Altova XMLSpy) automatically generates an Structured Query Language (SQL) script that can be exported and used to automatically build the structure of a conceptual model-compliant SQL database in a DBMS software.

5 GIS realization and filling-in in open-source software

As specified in the introduction, open-source software tools were preferred. In addition to the above motivations, open-source software offers a major interoperability (since they can easily employ open formats). Furthermore, they permit the access to the code and to the connected libraries for the customization of some tools.

DBMS PosgreSQL, with its spatial extension PostGIS and the graphical interface PgAdmin III, was used to manage the system (PostgreSQL 2016). Moreover, a connection with Q-GIS was realized, with purpose to see the data.

PgAdmin III and SQL language allow the implementation of triggers and other functions useful for data querying and analysing, and the realization of views for users and different uses, and, the semi-automatic filling-in of the data.

To fill the database, the main difficulty is linked to the integration between national and regional data structures and the data structure suggested by INSPIRE and used to create the proposed GIS. Indeed, the provided data are often released as single shapefiles, and they are not organized in a systematic database.

6 Test site and available data

In order to test the functionality of the proposed GIS, the data of Sardinia (Italy) are used. In particular, the area of the Park of Sulcis, in the south-west of Sardinia, is considered.

For this specific area, several data were collected, as information about forests, fuel models, hydrographical sources, roads and technological networks, command centre, operating centres, teams, meteorological data, hotspots and alarms. Other data (e.g. event) were not referred to real cases of forest fires, but they were hypothesized for testing the system.

Each data set was therefore converted according to the designed database structure.

7 A specific TRIGGER function for early warning

In order to allow a real-time monitoring, a trigger system was developed and included in the platform. The triggers are ad hoc procedures for the automatic manipulation (insertion, modification and deletion) of the information related to an event (Perry 1990). In this study, a dedicated trigger devoted to initiate the sending of a first operation team on the field when receiving the alarm is proposed (Fig. 7).

The trigger was built in SQL code. Analysing the single phases (Fig. 8): the event starts due to an alarm (1). The alarm is given when the command centre is contacted, and some data are communicated and inserted into the system, among which the fire location (geographic coordinates) (Fig. 9); the system requires some variables to be defined as a reference for performing the following steps (2). The database selects the Command Centre in charge based on the field "country" where the alarm is given (3). Through the computation of minimum (linear) distance ("min distance" function), developed based on coordinates of the alarm, the nearest Operating Centre is selected (4). The Operating Centre sends the first Operating Team in field (TIF0) (5).

In order to exploit the advantages of such a GIS, different queries can be performed where the goal was the automatic calculation of the number of fire-fighters to be sent on the field. The variables considered by the automatic query are as follows: the class of fire, the teams that are already in the field and the availability of further fire-fighters in the nearest operating centres. A further parameter to be considered for calculating the number of needed fire-fighters is the extension of the fire. This can be assessed also in real time through some recently proposed methods (Vivalda et al. 2017b). At present, it is an automatic but independent task; however, future work could permit to fill-in the needed variables in the here proposed query with the fire extension forecasting results. Moreover, a network of physical sensors communicating with the built GIS could give real data about the development and extension of the fire.

Another interesting issue to be considered for determining the number of needed fire-fighters would be the presence on the territory of some additional risks or elements that could intensify or influencing the fire development (e.g. gas stations, nuclear plants and industries).

However, since the objective of this study was the development of an expeditious procedure and tools for fire management considering the whole Europe, these aspects, dealing with a major detail in the analysis, will be further developed in future researches.

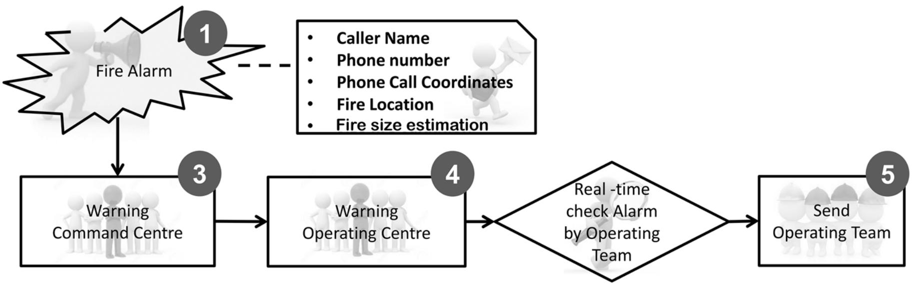

Fig. 7 Flow chart for developing alarm trigger

```
CREATE OR REPLACE FUNCTION "AF3"."TF_Alarm"()
RETURNS trigger AS

$BODY$DECLARE

CCID character varying(5);
OCID character varying(20);
OTID character varying;
DIST double precision;
NUMBER integer;
BEGIN
SELECT A."CommandCentreID" INTO CCID
FROM "AF3"."Command Centre" AS A
WHERE A."Country" = NEW."Country";

SELECT A."OperatingCentreID" INTO OCID
FROM "AF3"."Operating Centre" AS A
WHERE  A."CommandCentreID"=CCID AND
"AF3"."Distance"(NEW."Latitude", NEW."Longitude" ,A."Latitude",
A."Longitude")=(
       SELECT MIN("AF3"."Distance"(NEW."Latitude", NEW."Longitude"
,B."Latitude", B."Longitude"))
       FROM "AF3"."Operating Centre" AS B
       WHERE B."CommandCentreID"=CCID)
LIMIT 1;

INSERT INTO "AF3"."OperatingTeam"
("OperatingTeamID","CommandCentreID" ,"OperatingCentreID" )
VALUES (OTID,CCID,OCID);
RETURN NEW;
END;
$body$ LANGUAGE plpgsql;
CREATE TRIGGER alarm_commandcenter BEFORE INSERT ON "AF3"."Command Centre"
  FOR EACH ROW EXECUTE PROCEDURE "AF3"."TF_Alarm" ();
```

1 Process starts: Alarm

2 Variables definition

3 Select "Command Centre" by "Country"

4 Select "Operating Centre" by "Distancefunction"

5 Insert of new record in "OperatingTeam"

Fig. 8 Alarm trigger SQL code

The query is composed by two iterative processes (the two loops), which finish only when the number of men in the field is sufficient to fight the developing fire (and this last one is no more increasing) (Fig. 10).

When the trigger in Fig. 7 creates a new team (TIF0) after the alarm, a new event in EventRegistry is inserted and the HotSpot coordinates are registered.

This query is used when a new update on EventTime table arrives to the Command Centre. Generally, rises of Rate of Spread (ROS) and intensity of fire in EventTime table produce a new request of fire-fighters (Andrews and Rothermel 1982). When the ROS is constant or decreases the loop stops. To simplify the process, in this case, only the ROS was considered. Therefore, the query takes into account the ROS of the Event and selects a proper value of "class of Fire". The fires are classified considering the control problems on

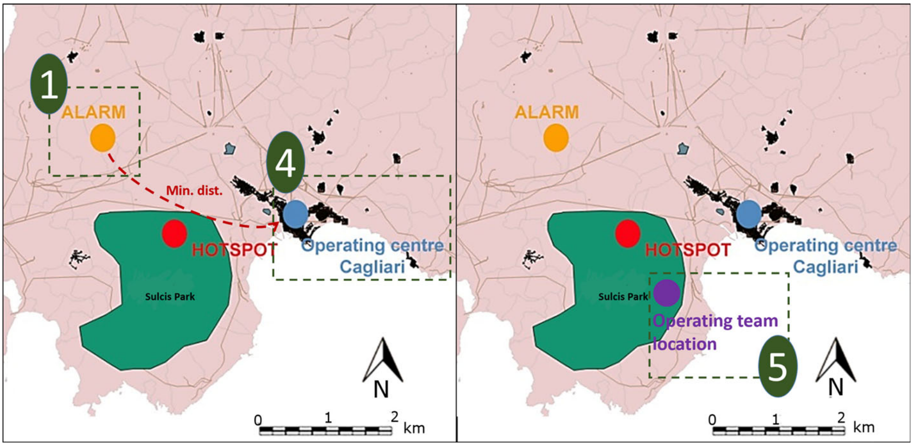

Fig. 9 Trigger in Q-GIS (the numbers refer to the trigger steps in Fig. 7, and the output of them is underlined in the green squares): (1) input of the alarm position in the system, (4) selection of nearest operating Centre based on "min distance" function, (5) creation of new operating team (TIF_0). The TIF_0 position would be surveyed and mapped during the operations through navigation sensors communicating to the system. The numbers refer to the SQL code described in Fig. 8

each kind of fire (Cesti 2002). As a consequence, it is possible to define the number of the needed fire-fighters (NF).

Once the query is performed, the first loop updates the class of fire and checks if the number of fire-fighters on the field (TIFt) is sufficient, compared with the needed fire-fighters (NF). If the result is negative, the second loop starts, verifying if the fire-fighters availability, in the nearest Operating Centres, allows to cover the request of support, and so on considering the Operating Centres in order of their (linear) distance from the fire. The loop stops when the request of support is totally covered. The query, in this way, updates Operating Centre Resources and allows to know who is on field, how many men, and when, they are involved in the fire management. The time saved by means of such tool is very precious in an emergency case.

8 Conclusion

In the paper, a standard-compliant and integrated GIS was proposed, as the core part of a more complex system for "big fire prevention and management", an SDI able to support prevention, preparedness, emergency response and recovery phases of the fire-fighting process. It can support early warning systems, the integrated management of historic data and dynamic information, which is a critical challenge, especially when considering the intensification of fire phenomena, because of the climate changes, and when it comes to the so-called mega-fire. It is aimed at filling the existing gap in the fire-fighting process, in the integration of a very heterogeneous information (multiplicity of procedures, used data formats, used data sources and so on). The cartographic and territorial data very often do not comply with shared standards, so they suffer from a limited interoperability. This study proposes a solution by means of the interoperability technologies, developed in a "smart" framework.

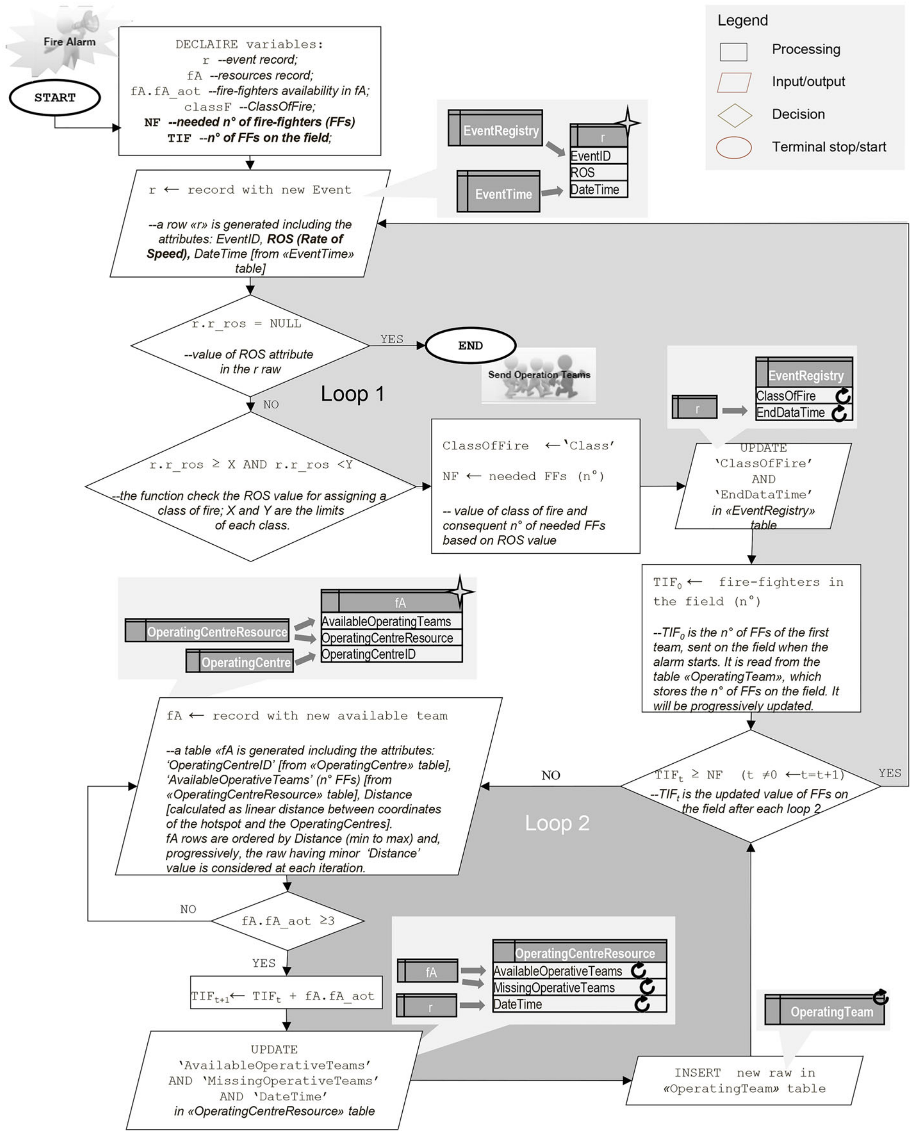

Fig. 10 Schema of the query workflow. The SQL code of the query is shared at the link http://areeweb.polito.it/geomatics_lab/Download.html

A great advantage of the proposed system is the use of the available reference standards for structuring the data and the metadata referring both to the cartographic side (land shape, land coverage and use, network and infrastructures, etc.) and to some thematic environmental or monitoring data. This makes the system completely compatible and importable by states having INSPIRE-compliant digital maps, as should be in the near future, for states having adopted the INSPIRE Directive (the whole Europe). Being the INSPIRE data model structured in form of a very general and application-independent ontology, it could be probably exported to further regions with effective results.

Furthermore, the inclusion of dynamic data, historic data registry and similar information can be an effective support to advanced analysis, to be performed directly in the GIS platforms.

Another contribution of the presented study is the effort to improve the automaticity in the conversion of the (in this case extended) conceptual model into the internal model. In this way, during the transformation from an object-oriented UML class diagram to the object-relational PostgreSQL/PostGIS database, the data formats and semantics defined by INSPIRE are preserved. A modelling phase in Enterprise Architect was employed for defining the extension, which is already affirmed practice in the community. On the other hand, while the use of an MDA approach is probably affirmed in the informatics field, for geomatics and cartography management goals, it has to be refined and tested. Although being an essential part of the generation of the now unavoidably standard-compliant geodatabases, an optimized procedure implementing is not fully integrated in the software yet.

Finally, an innovation of the system is linked to the specific application field. The more critical limit is the lack of integrated and harmonized procedures, solutions and data for common analysis and optimized management of the entire command chain in interventions for fire-fighting. In the functioning of the GIS, a solution was hypothesized considering a unique control centre holding the task of coordination and management, and distributing responsibilities and mission instructions to decentred bases, able to act. A more definitive solution should be obviously proposed by the entities directly involved in the fire-fighting application field.

A great part of the system was based on the open-source system, but some tools are only available under shareware software, which still limits sometimes the full understanding of some processing.

In future work, the proposed platform should be tested in collaboration with the actual operators intervening in the fire-fighting. Moreover, the implementation of automatic procedures should be improved. A fundamental part of such automatic procedures should regard the fire alarm, which could be given by automatic physical sensors positioned in especially vulnerable areas (as evaluated by experts). In this way, an effective sensor network architecture, following the Internet of Thing paradigm, could be exploited and integrated in the proposed tool (Gubbi et al. 2013; Arco et al. 2016). A fundamental development will be the publication of such system as webGIS or as part of a more complex SDI.

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