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Emergency Support System: Actionable Real-time Intelligence with Fusion Capabilities and Cartographic Displays

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Abstract:

This paper describes the Emergency Support System (ESS), which is an FP7 European Project (funded from 2009 to 2013), as well as a suite of real-time (spatial) data-centric technologies, which will provide actionable information to crisis managers during abnormal events. The approach guiding the ESS project and architecture is based on the fusion of variable forms of field-derived data, including data obtained from unmanned aerial vehicles (UAV), unmanned ground stations (UGS), air balloons and cell-phone trackers (IMSI catcher), as well as on data obtained from external Web services (supplying mostly spatial data and functionality based on spatial data) and external crisis management systems (e.g. command and control systems). Fused data are visualized on the ESS portal.

Keywords:

Data fusion, Sensor Web Enablement, Cell-phone detection, Cartographic visualization, Crisis management.

1. Introduction

Modern societies are confronted with an increasing number of abnormal events, crises, disasters and catastrophes. Such extreme events are marked by threats to the values of society and/or its life-sustaining functions and create an urgent need to respond to such threats under conditions of extreme uncertainty. In the case of an abnormal event, it is the responsibility of public authorities to manage the response operation in order to

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save lives and restore a sense of order. Without accurate information, crisis managers find it hard to make fast and correct decisions. In fact, the absence of reliable information tends to have a paralyzing effect on decision-makers in a crisis situation. The risk of making decisions based on partial, non-verified information may have unintended effects, which may fuel rather than dampen the crisis and thus delay decision-makers from taking necessary steps.

The Emergency Support System (ESS) as an FP7 European Project (funded from 2009 to 2013) including a suite of real-time (spatial) data-centric technologies aims to significantly improve this situation (for more information about the project see [1]). The ESS consortium (consisting of 19 partners) is developing a revolutionary crisis communication system that will reliably transmit filtered and re-organized information streams to crisis command systems, which will provide the relevant information that is actually needed to make critical decisions. The information streams in ESS are organized in such a way that they can be easily enhanced and combined with other available applications and databases. ESS provides an open API (Application Programming Interface) in order to allow any public authority, if needed, to add more applications customized to its particular needs. ESS data, functionalities and data flow are based on ISO, OGC, W3C and industrial standards. Therefore, each application which has adopted or will adopt these standards is able to connect to ESS – e.g. [2] or [3]. In order to validate the system, four field tests (defined in cooperation with end users of crisis systems) will be undertaken: a proof-of-concept field test, a fire in forested area, an abnormal event in a crowded stadium, and a toxic waste spillage accident. Operating ESS under different scenarios is necessary in order to test the system's capabilities in different kinds of crises using a variety of collection tools.

The following sections describe the overall architecture and the proof-of-concept field test from 2010, and present a brief overview of subsequent ESS development.

2. ESS Architecture

ESS architecture [4] is the basis for developing the Emergency Support System. For this reason, it was analyzed from several points of view:

- functional and non-functional requirements model,
- components derived from the requirements and the relationship matrix,
- detailed component design model,
- use case and dynamic model,
- detailed description of fundamental architectural aspects that shall be taken into account for the major ESS layers sensing, service and portal as well as ESS alert system.

Only overall component model architecture will be described further due to the limited extent of this article.

The ESS component model provides an overview of the high level architecture of ESS. The main purpose of this model is to define the organization and dependencies of the system components. External components are modelled as well in order to improve the understanding of ESS boundaries and potential interactions with external systems as described above. The architecture depicted in Fig. 1 is not a monolithic package, but a system consisting of components and subsystems. Note that not all aspects of the architecture are covered herein.

As depicted in Fig. 1 above, the Emergency Support System consists of three main subsystems: Data Collection Tools (DCT), the Data Fusion and Mediation

System (DFMS), and the ESS Portal. ESS integrates several existing front end data collection technologies into a unique platform, which is the primary task of Data Collection Tools. Besides inputs from DCT, other inputs (such as external Web map services, non-ESS resources and simulations) are intended as well.

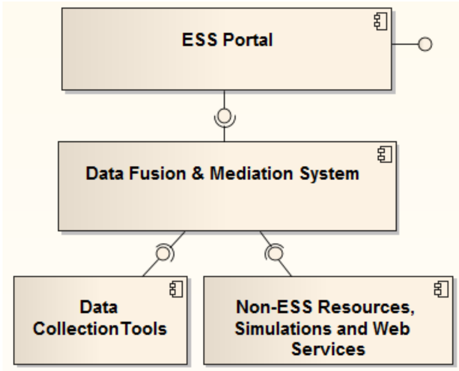

Fig. 1 Emergency Support System architecture – main components and subsystems

DFMS – as defined in [5] – is the centralized subsystem working over the ESS database, which is connected to all front end sensors and other resources activated in or connected to the system. DFMS oversees communication between sensors and the database, data harmonization from various sensor products of one type, the fusion of data from various types of sensors, spatial data localization, and the transmission of data to the ESS Portal subsystem via standardized interfaces. Intergraph CS, as one of the industrial partners, is involved in most of the project tasks including WP5 (DFMS) leadership.

The ESS Portal is the client application of the DFMS within the Emergency Support System. It represents the user interface which contains all graphical components, contextual components, log access, etc. and manages data exchange between underlying layers. It provides functionalities to export data from ESS to other systems. The ESS Portal can provide any kind of functionality to external systems on the basis of its internal capabilities. These "applications" are offered in the form of Web services.

2.1. IMSI Catcher Data Harmonization

IMSI (International Mobile Subscriber Identity) catcher is a crucial ESS component for real-time people presence information. It will be described in detail since it is not a usual component of current emergency and crisis management systems, and highlights one of the main differences between ESS and other supporting systems for crises events. In fact, it does not determine the location of a cell-phone, but only its distance from the catcher within a certain angle of view. The distance is determined only approximately – per sectors of length 550 m for the GSM network or about 50 m for UMTS (depending on the kind of a network), as depicted in Fig. 2. For example, IMSI catcher can say that phone C_2 is located at a distance of 1100-1650 m from the catcher position.

The phone's location in space must be calculated according to further known attributes. The catcher is directed to azimuth A and covers the triangle area given by angle of view F. Thus, knowing the distance range of a phone, the area in which it is located can be determined. For example, in the case of phone C_2, the area is bounded by a polygon given by points P_3, P_4, P_5 and P_6. It is evident that the greater the distance between IMSI catcher and phone, the more extensive the area giving the location of the phone is.

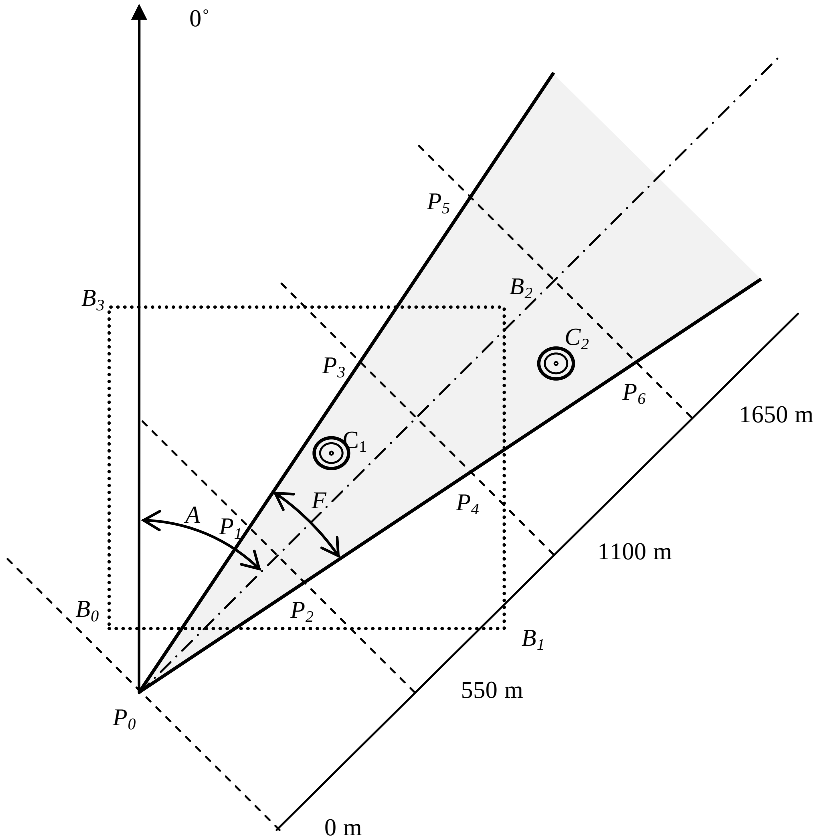

Fig. 2 IMSI catcher visibility

Determination of the number of people in a given area is based on the calculation of intersections between the area of interest and areas where phones were determined. For example, suppose that there is a need to determine the number of phones in a rectangular area given by vertices B_0, B_1, B_2 and B_3. To do this, areas which intersect the area of interest are searched for. In this case, there are three areas: P_0-P_2, P_1-P_4, and P_3-P_6, corresponding to distance ranges of 0-550 m, 550-1100 m and 1100-1650 m, respectively. There is no phone in area P_0-P_2. Each of the next two areas contains one phone. The area P_1-P_4 is fully covered by the area of interest; thus phone C_1 is certainly located in the area of interest. The area P_3-P_6 is not fully covered by the area of interest; thus the possibility that phone C_2 is located in the area of interest can be expressed only with a lower degree of certainty. The certainty is given by the ratio of the surface of area P_3-P_6 to the surface of its intersection with the area of interest. In this case, the ratio is 0.37. As a result, the area of interest contains 1.37 phones.

Note, that the azimuth of IMSI catcher can be changed in order to cover a broader area. The change of azimuth is usually smaller than the angle of view to ensure that the whole area is covered. It results in overlapped areas being scanned by IMSI catcher, as illustrated in Fig. 3. Then, the same phone C can be detected in more than one area. Such possibilities must be eliminated in order to provide correct results; one way of doing this is to eliminate duplicate cell-phones according to a unique identifier (i.e. an IMSI number).

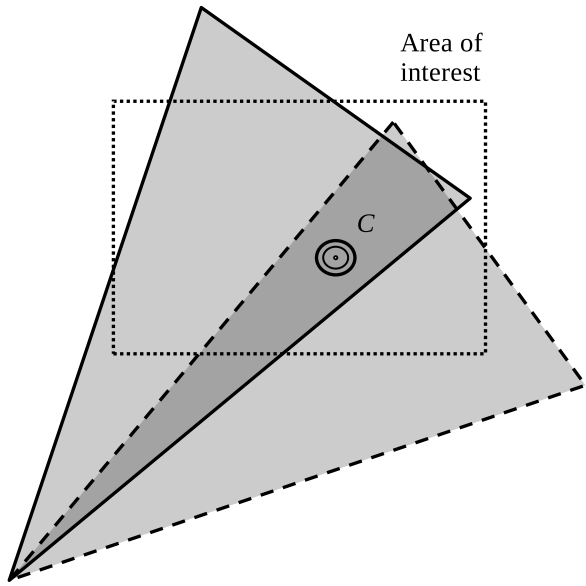

Fig. 3 Overlapped areas

2.2. Calculation of People Density of an Area

The calculation of people density in an area is based on the presumption that each person has his/her own cell phone. Thus, the number of phones detected in the area corresponds to the number of people in the area. People density D of an area A can then be easily calculated using formula (1) below, where P_A is a cell-phone in area A and E_A is the extent of area A.

$$D = \frac{\sum P_A}{E_A} \qquad (1)$$

3. Proof-of-concept and its Scenario

3.1. Purpose and Description

The proof-of-concept (POC) system and field test were devised by integrating essentially off-the-shelf components (COTS) provided by partners. This was a challenging task due to the highly different technologies of the partners, the continuously evolving requirements of end users, and the relatively short time devoted to POC development. The main goals were to evaluate the general idea of combining all ESS components, their individual functions and integration, as well as the entire system and its data flow. The POC system development took almost one year (from June 2009 to April 2010), while the field test was carried out at Bengener Heide Airfield in Germany between 7th and 10th June 2010.

3.2. Scenario

As mentioned above, the ESS has four main scenarios, of which the proof-of-concept scenario is the first one. The following section describes the proof-of-concept scenario as planned by consortium partners and external advisors from crisis and emergency management fields.

11:00: A person at the front end calls 112 and reports burning containers containing possibly toxic materials, which have fallen from a van or truck. These burning containers are located at the Bengener Heide Airfield, according to the first responders. The 112 operator asks for further information and requests that the caller move to a safe zone. The incident commander alerts the relevant responding agencies and authorities (e.g. special units dealing which chemical spillages are called in to support fire fighters).

Fig. 4 ESS base equipment (from left): meteorological sensors with INCA modem, unmanned ground station (UGS), unmanned aerial vehicle (UAV), IMSI catcher

An intelligence officer and fire fighters arrive at the scene at 11:05 and establish a mobile command post with the Emergency Support System. The intelligence officer opens the portal and enters preliminary information about the incident in the ESS Portal (2D and 3D maps, traffic and sensor information, the location of people from IMSI catcher). The incident commander also arrives.

11:05: The incident commander receives information from the officer-in-charge. He inspects the information and orders fire fighting measures to be delayed until measurements of toxic substances have been taken. The incident commander classifies the incident as difficult to survey and potentially dangerous; therefore, he orders mobilization of the ESS-vehicle. After having checked the circumstances for intended use of ESS-equipment (see Fig. 4), he chooses an appropriate configuration of ESS-vehicle with special sensors, cameras, UAV (unmanned aerial vehicle), balloon and IMSI catcher.

11:10: The officer-in-charge receives sensor information about the toxic compound. Subsequently, the incident commander instructs the intelligence officer to use the ALOHA system in order to predict the size of the toxic cloud (given the type of toxic substance), the estimated volume of the barrels on the van, and the weather conditions (according to data from nearby ESS weather sensors).

11:14: The intelligence officer enters the cloud characteristics into the Emergency Support System according to the results of the ALOHA model. The incident commander checks them on the screen. He instructs the officer-in-charge to mark the hot and warm zones accordingly. He asks the police to block the motorway in both directions, choosing junctions where the cars can conveniently turn.

11:15: The incident commander checks the information prepared by the intelligence officer to get an overall picture of the situation. This step includes:

- potential facilities to evacuate (educational facilities, facilities for people with special needs),
- hospital availability (whether hospitals can accept urgent cases or not),
- the presence of the various units which the intelligence officer has called in, as confirmed by the police,
- further pictures from the scene, e.g. showing the zones,
- traffic information.

11:20: After the ESS-vehicle has arrived, the UAV is launched to get an overview and to decide where to position the sensors and where to take measurements. The incident commander issues directives for positioning UGS (unmanned ground stations) after having seen the videos from the UAV. The staff set up the UGS between hot and warm zones to take measurements and monitor the scene. The mobile IMSI catcher is positioned to detect people with cell-phones in hot and warm zones. The ESS car is deployed to take various measurements in hot and warm zones. Its position can be tracked within the ESS Portal.

11:25: The incident commander checks the position of ESS-equipment and watches the UGS-videos, camera pictures and sensor data via ESS.

11:30: The incident commander is notified via the ESS portal that cell-phones have been detected in the hot zone.

11:35: The incident commander activates SMS alerts to the cell-phones detected in the hot zone instructing the users to immediately move away. The UGS video detects one person in a car on the runway.

11:37: The incident commander checks data from the sensors. Chemical sensor data do not exceed threshold values; therefore, the fire brigade is told to start extinguishing the fire (which can be observed by the incident commander on the video).

11:45: The incident commander detects that there are still cell-phones within the hot zone. He orders that the users be alerted with a phone call and located through UAV.

11:50: A car is detected on the UAV video close to the motorway. The incident commander informs the ambulance to rescue the driver.

12:01: Suddenly an alarm is given that, according to values obtained from an ESS chemical sensor, a threshold value has been exceeded. Coloured smoke is seen on the UGS video. The incident commander instructs the fire fighters to stop fighting the fire and to treat the toxic leakage.

12:05: The sensor values are below the threshold value again. The incident commander instructs the fire brigade to resume fire fighting. Special units dealing with chemical spillages take the first steps towards decontaminating the area.

12:15: A final check via the ESS-equipment confirms that all values are within the normal range again.

4. Field Test

4.1. Field Test Preparation

Several tests were made at various locations in the first half of 2010 before the field test was performed. At the same time, permission from several authorities was needed in order to conduct some of the tests – such as permission to operate the IMSI catcher, permission for the UAV to fly in the specified area, etc. Unfortunately, permission to operate the IMSI catcher in a commercial phone network was not granted (in Germany such permission is subject to legal adjudication); therefore, the whole scenario was tested using private cell-phones from members of ESS consortium. The German Bundesnetzagentur (The Federal Network Agency) monitored the usage of IMSI catcher in a preliminary test, as well as during the field test.

The main test of ESS proof-of-concept was demonstrated at the Bengener Heide Airfield at Bad Neuenahr, Germany. The field test was planned over a period of four days. The first day was dedicated to system installation and testing; on the second day, a "dry run" of the scenario, and further configurations to the system were made; on the third day, a demonstration was presented (with feedback from independent observers); and on the last day, internal evaluation was done. The POC field test was attended by 24 independent observers representing the European Union Satellite Centre, the Federal German Ministry of the Interior, the Department of Defense Analysis in Sweden, the Spanish Air Force, the German Bundesnetzagentur, German Air Traffic Control, the Bavarian Bundeskriminalamt, the German Armed Forces, Italian Firefighters, Dutch aviation companies, and two regional newspapers.

4.2. Field Test Realization

The ESS proof-of-concept field test was conducted according to the scenario described in section 3.2 of this paper. The realization phase used all components mentioned in section 2, except for the air balloon and with the proviso that the IMSI catcher was not used in the public cell-phone network due to the limitations described in section 4.1. The final field test was carried out between 7th and 10th June 2010, i.e. within four days as planned. Two videos – the first about ESS in general and the second about the ESS proof-of-concept field test – are located at the following URLs:

- http://www.intergraph.com/global/cz/assets/videos/ESS_General.wmv
- http://www.intergraph.com/global/cz/assets/videos/ESS_Doco_gen.wmv

As a deviation from the final system architecture, cell-phone data from WIND (one of the project partners) could not be provided as a source of live traffic information. It was primarily assumed that also real-time traffic data would be obtained from the cell-phone network – in this case from the cell-phone network operator (i.e. while using the BTS – base transceiver stations – approach). Unfortunately, the field test site was not covered by the phone operator WIND.

The POC showed that all hardware and software platforms used within the ESS project can be integrated and work together in the context of a whole system. This project phase used FTP (File Transfer Protocol) servers as a simple tool for communicating between various legacy systems and for injecting information into the database. The ESS Portal was able to visualize all information stored in the DFMS database.

The development of open interfaces is crucial for the further success of the Emergency Support System – in particular, for it to be ready for future field trials. It was intended that proof-of-concept would be conducted on proprietary interfaces, protocols and formats, while the final system would be based on international (mainly ISO, OGC and W3C) standards. One of the project conclusions will therefore be a comparison of proprietary and open interfaces. Besides defining open interfaces, the proof-of-concept will serve as one of the inputs for further ESS development. The following paragraphs briefly describe the main developments that are planned for the basic ESS subsystems.

Data Collection Tools (DCT) will need to resolve software bugs and wrap data communication into the SOS (Sensor Observation Service) framework. WLAN was used to transmit sensor data in POC. However, an extension to the INCA modem has to be made for effective wireless communication with multiple sensors.

The Data Fusion and Mediation System (DFMS) was based on the Oracle database and FTP server in the POC phase, while the final architecture requires development of a new client for the SOS interface between DFMS and DCT. In particular, issues relating to error detection and repair, tracking data provenance and usage, and computing people presence information have to be resolved because most of the sophisticated DFMS functionality was not intentionally planned for the POC due to the complexity of the tasks involved and the limited time for the first version of the system to be created.

The ESS Portal (see Fig. 5 above for POC visualization examples) needs to enhance its functionality mainly with respect to the feedback from POC independent observers. At the same time, further services have to be integrated: the IMSI catcher as another alert service, a traffic simulation system, a service for IMSI/IMEI-MSISDN matching, and a 3D cartographic viewer with the ALOHA model (since the ALOHA model has only been implemented in 2D so far).

4.3. Field Test Assessment

As was written above, the POC field test was attended by 24 independent observers representing various actors in Crisis and Emergency Management. These observers were the target group that gave us feedback about the field test. For that reason, each observer completed a short questionnaire that contained 6 questions. Answers to these questions are described in the following paragraphs.

Only 1 person (4 %) did not get a general idea of ESS development, while 23 observers (96 %) obtained valuable information about ESS in general, details on ESS components, information about the components' integration framework, and details about their operational approach. One remark suggested that our system was not fully suitable for operational approach as it was considered more as a system test. This (operational) approach will be the subject of future scenarios, which will be focused on tests involving real crisis management situations.

All observers rated the POC field test highly in terms of innovation and user requirements needs. Some of the highly appreciated aspects of the system were its fusion capabilities, its scalability, its resilience, the level of visualization, the position plotting of video targets, the use of satellite phone links in the case of terrestrial links becoming blocked, and the scheduling of rescue workers. A weakness can be seen in its high ambitions with respect to toxic gas detection – according to the independent observers, this was the only issue requiring a separate research and development project. More than one third of the observers were satisfied with the current version and would like to use ESS as it is – i.e. without waiting for more than two years for a final version.

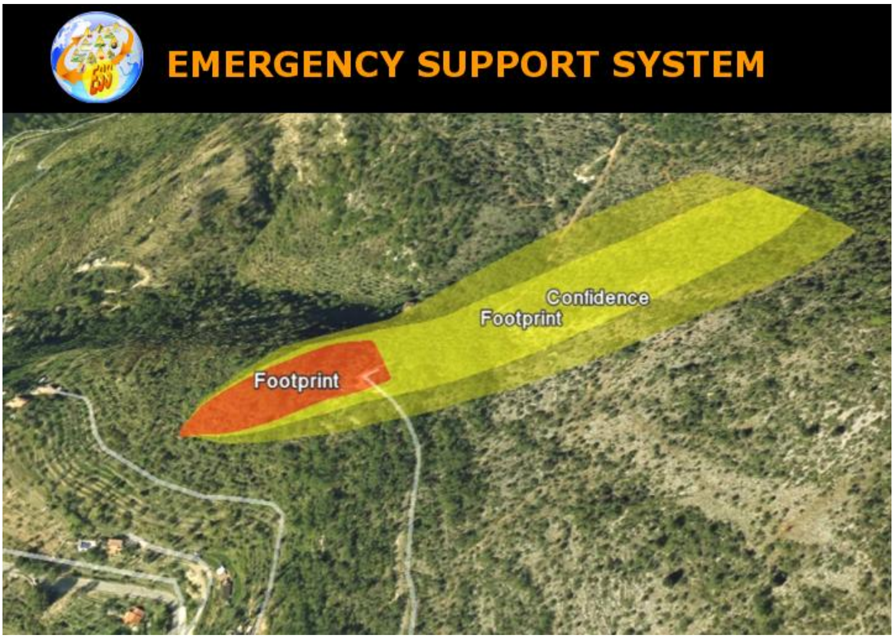

Fig. 5 ESS Portal as the visualization of the Emergency Support System (from top): view on the ALOHA model, results of people presence calculation (obtained from IMSI catcher)

The third question related to the functionality that should be improved in terms of innovation and need. Our observers mentioned open interfaces for exchanging data with different command and control systems, simulation and risk assessment systems (Command and Control Systems, C3I, C4I, etc.) as the most crucial. These requirements will be the subject of further development and were not intended to be features of the POC field test. Thus, it was expected that persons used to working in crisis and emergency management on a daily basis felt the lack of this functionality.

Extensions to the system in terms of technological innovation and operational need should – according to 75 % of our external users – include mainly the detection and repair of errors and gaps in sensor data. Further comment relates to the access to archived datasets to compare the situation before and after the crisis. Debriefing historical data was not demonstrated in the POC field test; however, it will be a part of ESS development.

The fifth question was on how the simulated scenario could be improved to test ESS in a more realistic event. In four cases, the low degree of complexity of the scenario was designated as the key limiting aspect, as real life situations would include the coordination of various types of rescue workers, as well as integrating actors in the field, field base actors and decision maker stakeholders.

The last question was devoted to the potential risks or hindrances in using an emergency system like ESS. Only one person indicated the use of ESS as extremely risky for electronic communication (maps, e-mails, alerts, etc.) in comparison to phone calls. All other observers evaluated ESS as applicable with minor potential risks – these risks were related to the special training needed to operate the system, purchase and maintenance costs, and disturbances of the cell-phone network during operation of the IMSI catcher. The last question revealed that legal restrictions and the obtaining of permission for operating various items of ESS-equipment seem to be one of the greatest obstacles. Also it was stated during the feedback session that an organization would share their data only with selected organizations and would need to know the sources of any information before trusting it.

4.4. Subsequent Development

The first (POC) field test of the Emergency Support System has provided much valuable experience that will influence the subsequent development of this system. First of all, it was foreseen that POC would be realized as an integration of essentially off-the-shelf components (COTS) from partners, where only one scenario would be assumed. The primary goal of this field test was to conclude whether this system was or was not applicable in real crisis management situations. According to the independent observers, as well as according to the project partners, the POC was well-organized and the consortium managed to integrate and visualize all components in the system.

The major development relates to the definition of interfaces. The final version of the Emergency Support System will be based on opened interfaces – resulting mainly from W3C (World Wide Web Consortium), ISO (International Standardisation Organization) and OGC (Open Geospatial Consortium) recommendations, standards and implementation specifications. The OGC Sensor Observation Service (SOS) in version 2.0 as a part of the OGC Sensor Web Enablement (SWE) is intended for transmission between Data Collection Tools (DCT) and DFMS. It should be one of the first implementations, since SOS 2.0 should be approved in OGC by the end of April

2011. Sensor tasking will be realized directly between the ESS Portal and DCT while using the OGC Sensor Planning Service (SPS) 2.0 implementation specification that was approved at OGC in February 2011. DFMS (as a main data store) will share several open interfaces with the ESS Portal to ensure the bi-directional transfer of information. These are: the OGC Web Map Service (WMS) for reference data (like orthophotos, base maps, etc.), the OGC Web Feature Service (WFS) with transactional support for mainly sensor data and OGC Filter Encoding (FE) to support the filtering capabilities of WFS queries. The repository for metadata descriptions of all ESS data sources was not realized in the POC phase. For this reason, it was decided for the final system to develop an OGC Catalogue Service for Web 2.0.2 compliant server with the support of ISO 19139 compliant XML (eXtensible Markup Language) encoding for metadata of datasets, (external) services as well as sensors (based on work of [6]). DFMS is the tool responsible for correct extraction of metadata and data from the SensorML (Sensor Markup Language) – encoding used within SWE standards. This way, it will be possible to automatically generate and update sensor metadata (including, for example, metadata from the IMSI catcher). The next field tests will compare the solution based on COTS and the one based on open interfaces.

Besides open interfaces, several recommendations for the subsequent development have been proposed. The system needs to be able to handle incoming garbage data. For this reason, several validation mechanisms are assumed – including networking, HTTP and XML validations (to achieve data consistency) and XSD, Schematron and application validations (to achieve data correctness). Simultaneously, status information for sensor data sources is needed. This step incorporates the status itself, (i.e. a sensor is online, transmitting, producing erroneous data, with low battery etc.) as well as a recovery procedure in the case of sensor failure. The fusion of various data sources also requires a common time framework for the effective synchronization of sensors, video and underlying telemetry data. As a solution, the ESS consortium uses GPS time as the unifying time platform. Even if data are received correctly and time-synchronized, they should be cached for network break down situations and for analyses after the crisis situation.

Spatial event processing was not implemented as a part of the POC field trial due to its complexity and the time needed for development. The final system should support a spatial event processing mechanism for the timeliness of information dissemination, as well as on-the-fly generation of higher-level information within ESS. To enable event processing in ESS, services need to realize a common publish/subscribe interface, which in our case is being realized through WS-Notification.

According to [7], the importance of cartographic visualization cannot be overlooked, especially for crisis management applications. Attributes within the data drive the portrayal process; however, there may be many various portrayals for the same data with identical attributes, as shown in Fig. 6 above. The example shown in this picture fulfils the concept of contextual visualization as described e.g. in [8].

5. Conclusions and Future Development

The Emergency Support System has successfully gone through the first – proof-of-concept – field test and it was demonstrated that it is capable of providing valuable information to enhance the functionality of existing Command and Control Systems (C3I and C4I systems respectively).

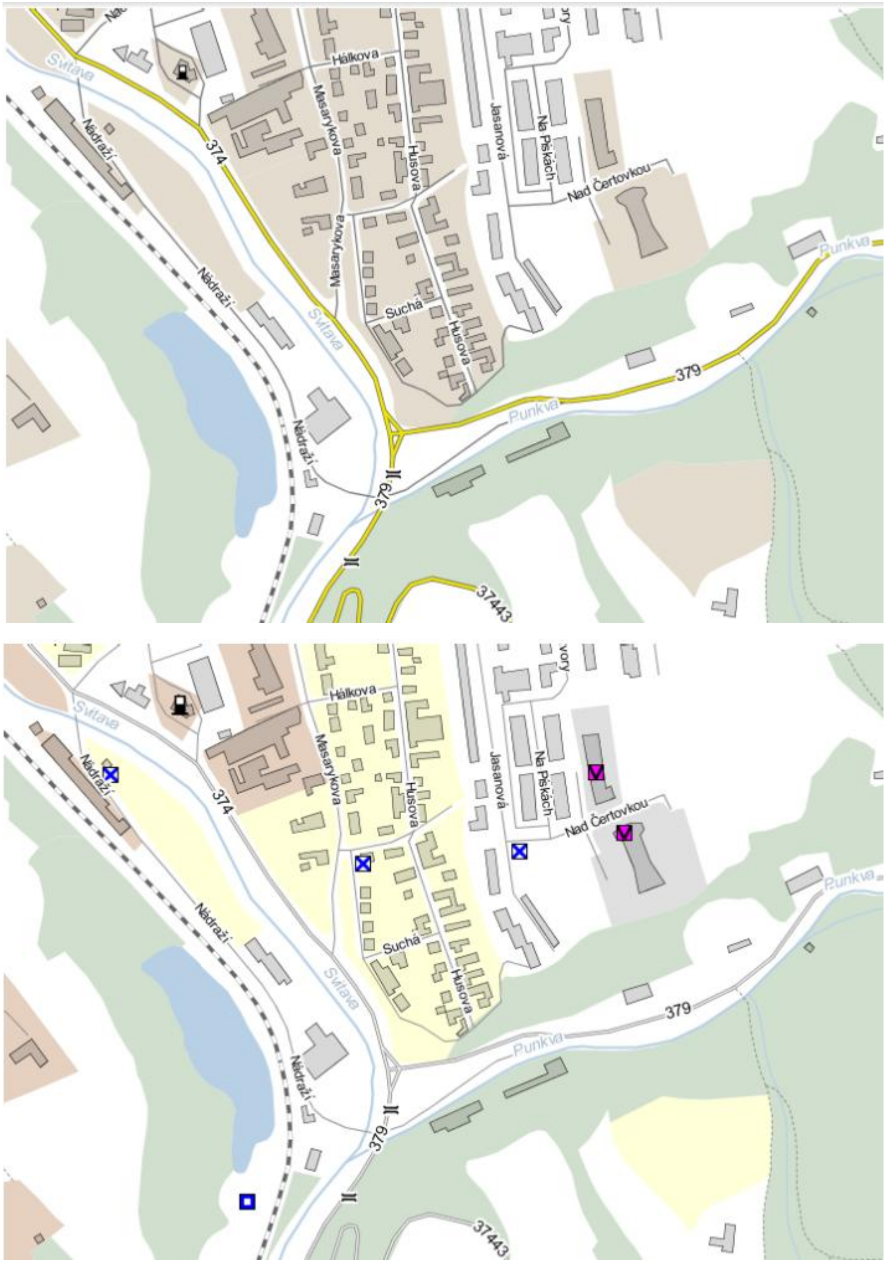

Fig. 6 Various cartographic visualizations for the same data (coming from the same database) and the same geographic area as defined in [8]

Although ESS applicability has been confirmed, work remains to be done concerning issues raised in the feedback from the POC field test (mainly focusing on hardware and software improvement, validation mechanisms, the archiving of historical data, resilience issues and the adoption of a spatial event mechanism), as well as the replacement of proprietary interfaces with standardized interfaces. Some of these standardized interfaces should represent some of the first implementations of such standards (e.g. Sensor Observation Service in version 2.0) and, for this reason, one of the following results will be a comparison of proprietary and newly designed open interfaces. On the other hand, a spatial event mechanism represents a completely new feature of crisis and emergency management systems. More attention (in comparison to the POC) will also be paid to the analyses of ESS integration into existing Command and Control (C3I and C4I) systems. Unfortunately, ESS integration into existing C4I systems is not the primary task in this phase of the project. On the other hand, ESS offers open interfaces dealing with the XML encoding as described above. Existing C4I systems use XML encoding as well, usually in line with the TSO (European Union) and EDXL (United States of America) standards. Such integration may therefore be based on the simple XML conversion using, for example, eXtensible Stylesheet Language Transformations (XSLT).

In addition to the new development described above, there will be a further testing phase planned for 2012 and 2013, which will attempt to thoroughly demonstrate the functionality of the whole system, as well as fix bugs discovered during future scenarios. The next version of the Emergency Support System (with open interfaces) is planned to be ready for the 30th November 2011, when the development of all sub-systems should be finished and the integration phase will take the leading role in the project.

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