Visual Synthesis of Evolutionary Emergency Scenarios

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Abstract. During an emergency situation, decision makers are faced with the problem to quickly analyze large amounts of data related to the involved geographical area in order to grasp a comprehensive overview of the scenario of interest and manage the response activities. The success of those activities heavily depends on the availability of tools which allow them to extract and adequately represent relevant and timely information out of huge sets of (georeferenced) data. During the last 15 years researchers have long strived to define geovisual analytics methods and techniques, which support decision making in time-critical emergency response activities, such as evacuation planning and management. Such methods allow domain experts to visualize the status of the crisis, plan the evacuation and address people towards vacancies in emergency shelters. However, several issues remain to be addressed especially related to the need to make quick decisions in case of emergency scenarios which evolve differently from what one was expecting and from the devised emergency management plan. The research we are carrying out is meant to define an innovative paradigm for human-(geo)information discourse, which could expedite the analysis activities needed to make decisions on crisis management actions. The integrated visual system we describe in the paper allows domain experts, decision makers and any other emergency operator to analyze qualitative data about a geographical area, which may change vigorously with respect to both time and space and whose size represents a critical factor in the efficiency of management activities.

Keywords: Interactive geovisualization · Emergency response · Scenario-based interaction design

1 Introduction

During an emergency situation, decision makers are faced with the problem to quickly analyze large amounts of data related to the involved geographical area in order to grasp a comprehensive overview of the scenario of interest and manage the response activities. The success of those activities heavily depends on the availability of tools which allow them to extract and adequately represent relevant and timely information from huge sets of (georeferenced) data. During the last 15 years researchers have long strived to define geovisual analytics methods and techniques, which support decision making in time-critical emergency response activities, such as evacuation planning and management [1–3]. Such methods allow domain experts to visualize the status of the

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crisis, plan the interventions and distribute on-site responders, plan the possible evacuation and address people towards vacancies in emergency shelters. However, several issues remain to be addressed especially related to the need of making quick decisions in case of emergency scenarios which evolve differently from what one was expecting and from the devised emergency management plan.

The objective of the research we are carrying out in this context is to provide experts and operators with applications and tools addressed to support and improve their ordinary and extraordinary activities [5]. To achieve that goal we aim to define an innovative paradigm for human-(geo)information discourse, which integrates different modalities of visualization and navigation with visual metaphors representing geospatial data as well as their aggregations/syntheses.

An initial phase of our research has been devoted to investigate geovisualization methods and techniques addressed to users of mobile applications. In that case the major issue originated from the small size of screen which hinders the object visualization and requires some means to better support qualitative representation of geospatial information. In [7, 8] a visualization technique named *Framy* was proposed which underlies applications for mobile devices to simplify the detection of relevant elements. By applying *Framy*, sets of data can be summarized and qualitatively displayed on mobile devices by means of visual aggregates thus overcoming the limitations due to the screen size. The technique has been successfully embedded in different mobile applications where the need of summarizing large amounts of data is relevant to obtain information about a territory, thus corroborating the claim that applications based on a visual analytics approach are highly suitable to visually elaborate and communicate significant information to mobile users [9].

The interactive visualization technique we present in this paper leverages many of the benefits of *Framy* and its ability to support real time analysis of large data sets, but has been especially conceived to support central emergency management activities. *Beyond-the-Screen* is in fact the result of a contextual inquiry the authors conducted in the field of emergency preparedness and response involving a group of professionals, who handle both remote sensing images and thematic maps, and make decision on the basis of the detected phenomena and the objects distribution.

The involved professionals reported that when performing emergency management activities, they explore a geographic area by repeated panning and zooming of the corresponding raster image, towards more detailed portions. When, a possible area of interest is detected, the analysis is deepened possibly through additional tools. Such tasks often may cause user's disorientation due to the loss of context and, in the worst case, may lead to task failure. In order to efficiently speed up such tasks it would be useful to interact with both a rapid overview of qualitative distribution of data of interest and a detailed portion of the image. This implies a proper management of time and space parameters associated with the object distribution also through qualitative syntheses of geospatial data and phenomena.

The *Beyond-the-Screen* technique represents a solution to this specific requirement. It limits this drawback by visually summarizing information of interest, which can be used by the user as a guideline in performing the assigned activity. Maps are used to represent together the observed phenomena and their related geographic areas thus offering a unified map-related view of data resulting from information seeking or analysis tasks. Moreover, it offers the capability of switching among diverse views to analyze the evolution of an emergency scenario and make appropriate decisions.

The paper is organized as follows. Section 2 explains the problem domain analysis and the derived requirements. Section 3 describes the proposed interactive visualization technique. In Sect. 4 the use of the visualization tool is illustrated through a realistic interaction scenario. Conclusions are drawn in Sect. 5.

2 The Problem Domain Analysis

The participatory design process we have performed to derive the evolutionary visualization technique we present, has been mainly inspired by Rosson and Carrol's scenario-based design method [10]. Scenarios of usage were in fact chosen as our primary design objects, thanks to their simultaneous ability to guide design and to facilitate usability evaluation and assessment during the iterative development process. Starting from a field study conducted within potential real contexts of usage, we in fact built scenarios of emergency management practices. Our target users were those who operate in the Command and Control Centers (Centro Operativo Comunale, COC) and make strategic decisions. In the following subsection, we discuss the fieldwork results, and we describe the envisaged problem scenario and the derived users' requirements.

The field study

In 2012 we started a collaboration with the Civil Defence Agency of the town of Montemiletto, in the South of Italy, which led to development of a spreadsheet-mediated collaborative system for earthquake management activities which allows on-site responders to cooperate through mobile devices, share portions of data, apply for resources in a concurrent and reliable manner, and obtain real-time status updates from decision makers [5, 11].

The active participation of stakeholders and the knowledge capitalized from the former study led us to replicate it, this time focusing on the emergency management activities as they occur in the COC. We performed a contextual inquiry on the use of software applications for emergency management and on the processes performed for real time management. The main goal of the inquiry was to gain a comprehension of the extent to which information technologies support analysis and decision making during the emergency response process. A survey questionnaire was initially submitted to participants. The 6 subjects who took the questionnaire had different backgrounds and different roles inside the COC. Then we started the observation of:

- the physical settings where collaborative activities for emergency management are performed (e.g., the number of offices involved, whether co-located or distributed),
- the data which are continuously collected and analyzed, the information derived from the analysis, and
- how such an information is used for decision making purposes.

The kind of emergency response activities most of the interviewees described followed predefined protocols, that mainly relied on the use of a Web GIS platform, named SIRIO [12].

As a result of our study, we were able to understand that in common crisis management practices, SIRIO is used to understand the current situation and its evolution, based on heterogeneous data collected from different sources (e.g., local sensors, camera-enabled cell phones, etc.).

However, as some of the interviewees also reported, the effectiveness of the derived decisions often depends on the capability to quickly grasp the priority areas of intervention and establish the shelters locations and the rescue routes which may lead people there. If the emergency area is wide, COC operators may be forced to a high number of zooming and panning operations, shifting from the area overview to the detailed view and vice versa until full comprehension of the crisis situation is achieved and decisions are made. Moreover, as the emergency response actions take place, decision makers keep monitoring the area, ready to arrange for corrective actions if needed.

The problem scenario

In order to formalize the requirements elicited from the interviews, we capitalized the knowledge gained from the fieldwork and envisaged a scenario of emergency management practices, from which we could start our brainstorming activity for the design of a possible solution. Based on that knowledge, we built a persona, who could represent the 'decision maker', and, we envisaged his tasks inside a representative interactive emergency response scenario.

Persona Gino Rossi is a 55 years old Chief of the Civil Defence Agency for Montemiletto. He is an engineer and has a deep knowledge about the territory and has been covering the present role for the last 5 years. Supported by a team of experts, he coordinates the COC and makes decisions regarding evacuation, triage and any other action which can minimize the total extent of losses in case of a crisis. Data coming from different sources (telephones, cellular phones, fax as well as remote sensors) are made available through the SIRIO software platform, which provides him with both an analytical description and a synthetic view of the event evolution, also in the form of graphical representation. During critical situations Gino is forced to quickly elaborate the collected data and make timely decisions.

Scenario

A 4.5 magnitude earthquake has shaken Montemiletto, in South Italy, at 3:30 p.m. The event has happened during summer, on Sunday, in a touristic zone including the gathering area no.1, with many visitors in this period. The COC is immediately activated and the supporting team of professionals and volunteers are put on the alert according to the intervention model of the emergency plan.

***Gino Rossi manages the conflicting recovery requests** coming from two on-site responders and makes appropriate decision on evacuees' destination.*
Gino is informed that today a music event occurred in that area, which attracted a higher number of visitors than expected. Therefore, the recovery actions scheduled in the original plan need to be dynamically adapted so as to face the crisis adequately. Approximately every 20 min he receives reports from the gathering areas.
At 4:15 p.m. he receives a data sheet from the gathering area no.2, where he reads a request for the recovery of 26 people at shelter no. 1. Gino asks the SIRIO GIS operator in his team to perform a number of zooming and panning steps to focus on the geographic area of interest, he approves the request and updates the number of

available beds at that shelter. At 4:35 he receives another request for 33 evacuees from the gathering area no.1 which is associated to the same shelter but he realizes that only 9 beds are left. The GIS operator zooms out to gain an overview of the surrounding areas and find an alternative sheltering site. He is then able to identify two possible shelters, one located to the North and the other to the East. After analyzing the derived information, through further zooming actions, Gino decides to redirect the 33 people to the northern shelter no. 3, which has still got 48 beds available and is closer to the gathering area no.1. He records the new data and notifies his decision to the on-site responders.

Finally, he asks the SIRIO operator to prepare a new report on the current status of the crisis management process, which is distributed to all the local responders. It includes the updates made to shelters no. 1 and no. 3.

***At the end day 1 Gino has a plenary meeting at the COC** to collectively evaluate the evolution of the emergency situation since its beginning and the actions taken so far. The series of reports produced after each intervention are analyzed by the involved experts and an estimate is made of the actions which may be required next. As a result of the meeting, Gino and the other attendees agree that new teams of on site responders should be sent to the gathering area no 1.*

User requirements

The depicted scenario gave us the opportunity to reason on what claims about current practices emerged. In particular, they indicated that

- it takes too long to analyze details of a given area and relate that information to the surrounding territory
- in situations like the one described in the scenario, historical information on the evacuees allocation process performed at a given time can only be analyzed through the produced reports.

In fact, the first general requirement that all observed evacuation management activities seemed to raise is the necessity of innovative tools to visualize spatio-temporal information about emergency cases, that would yield an improvement in the efficiency of the related activities and, hence, of the overall emergency management process, while preserving the emergency management policies actuated so far. A second general requirement, strictly related to the former, which is also represented in the scenario, is that the visualized information should be easily interpreted by emergency managers, also with respect to the geographic and the temporal contexts, so as to provide effective support to rapid decision making. Those aspects would also imply limited learning efforts by emergency operators and satisfy the further requirement to minimize training costs and time needed for the actuation of the envisaged transformation, which also resulted from the interviews.

Summarizing the results of the field study, we were able to understand participants' main expectations for the improvement of current response processes:

- an interactive visualization tool should be built upon the current emergency management processes, supporting existing centralized decision making policies, with the goal to improve the real time comprehension of the current situation and the analysis of how it evolved.
- migration towards such an enhanced system should be as smooth as possible to COC operators.

In the following section we illustrate how the *Beyond-the-Screen* interaction technique has been exploited on top of SIRIO GIS platform to achieve an evolutionary geovisualization system satisfying the described requirements.

3 *Beyond the Screen* Visualization Technique

The described problem scenario highlights possible flaws in the emergency management process related to the number of exploration actions that professionals have to perform on an interface to gain an appropriate knowledge of the crisis situation. Typically, operators accomplish their activities through repeated panning and zooming towards more detailed portions of the image under investigation. When a possible area of interest is detected, the analysis is deepened also by additional tools. The contextual inquiry conducted with a team leader and his field workers revealed that such a (boring) combination of panning and zooming with either compression (the so-called *overview-detail* approach) or distortion operations (known as *focus-detail* approach) presents relevant limitations both in time necessary to reach a goal, and in the amount of backward operations one has to perform when changing the point of view and the identified directions. In order to speed up such tasks it would be useful to allow users to interact with both a rapid overview of qualitative distribution of data of interest and a detailed portion of the image, with an appropriate tradeoff between the zoom level needed to visualize the required features on a map and the amount of information which can be provided through the application.

The *Beyond the Screen* technique represents a solution to this specific requirement. It has been conceived to support analysis and visualization of huge volumes of geospatial data by combining interactive GeoVisualization methods [3, 4] with advanced computational techniques to support data exploration and decision-making processes. Moreover, it inherits the rationale underlying the *Framy* visualization technique [8] designed to face the limitation of the screen size of mobile devices exploiting an interaction metaphor for painting frames meant to provide hints about off-screen objects.

The *Beyond the Screen* technique adopts a similar approach by superimposing a frame to the currently displayed portion of the image, and adapts it by adding new features that guarantee a continuously available overview overlapped with a differently-scaled area under investigation, where the qualitative information is independent of the zoom level.

Given a buffer zone whose width can be either manually fixed or computed according to some parameters, the frame featuring *Beyond the Screen* is partitioned into several portions, corresponding to different sectors. Each sector is colored with a different intensity depending on both the quantity of POIs distributed within each map sector of the whole buffer zone, namely in-/off-screen objects, and the areal distribution of phenomena occurred within each map sector, expressed as the quantity of selected pixels in a raster image. It is also possible to customize the aggregate function by combining information from different layers thus improving the analysis results. As an example, a land use image can be overlapped with a vector theme and, on the basis of weights assigned to the different categories of land use and the presence of specific POIs (e.g. urbanized items), it is possible to identify and monitor zones with building constraints.

Figure 1 shows the adopted approach. It illustrates an area of interest partitioned into 8 sectors, *Pov* represents the center of the part of image displayed, S_i identifies the *i-th* sector and C_i is the corresponding frame portion. When the focus changes, *Pov* moves and the aggregate function is performed which first elaborates the value to assign to each S_i and then translates it into a color intensity associated to each corresponding C_i. The aggregate function associated to the frame calculates the target values independently of the part of image currently displayed thus guaranteeing an *ad hoc* overview cut out on the basis of objects and phenomena to display and properly balanced by the underlying aggregation function associated to the color intensity of the frame.

Fig. 1. The image partition according to the *Beyond the Screen* technique

As for the technological solution, *Beyond the Screen* is a server-side application interacting with SIRIO and has been developed as a Java project where classes mutually correlated have been packaged together. The most relevant modifications have been applied to the JMapViewer class of the OSM project [6].

4 Exploring Emergency Scenarios Through *Beyond the Screen*

To demonstrate the effectiveness of the proposed interactive visualization tool as a further support to centralized analysis activities and decision making, we performed a formative usability evaluation and tested *Beyond the Screen* prototype using an interaction scenario, which resulted from the transformation of the problem scenario described in Sect. 3. Again, at that stage we were able to rely on the active participation of the six subject who had responded to the initial questionnaire and gave us useful feedback on the appropriateness of the proposed technique.

Gino Rossi manages the conflicting recovery requests.

Gino has to modify the recovery actions scheduled in the original plan to face the crisis adequately, due to the fact that a higher number of people than expected was in one of the impacted zones.
At 4:15 p.m. he receives a data sheet from the gathering area no.2, where he reads a request for the recovery of 26 people at shelter no. 1. Gino asks the SIRIO GIS operator in his team to visualize real-time information about the geographic area of interest. Upon analyzing the situation, he approves the request and updates the number of available beds at that shelter.

The initial interface of *Beyond the Screen* is shown in Fig. 2. Displaying only the horizontal menu bar and the zoom slider one can visualize the widest map size. This approach satisfies the requirement of an initial overview to be offered to the user so that he/she can immediately recognize the area. The menu bar contains five buttons to invoke the application functionality as follows.

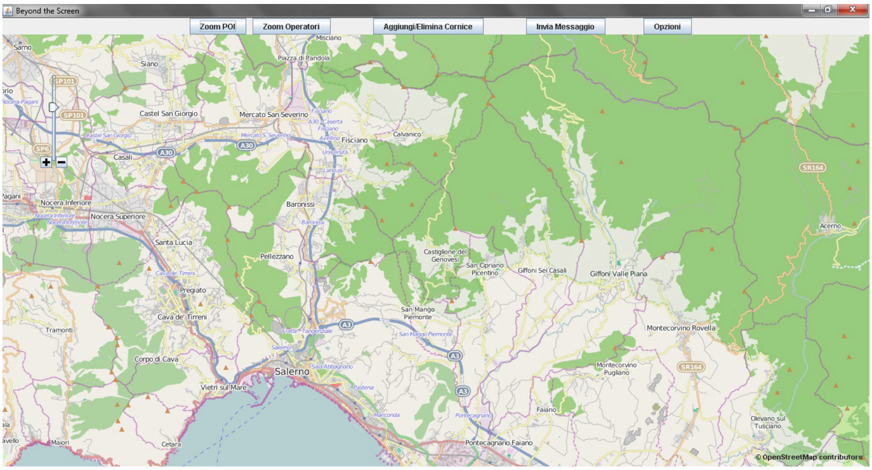


Fig. 2. The Beyond the Screen scenario

'Aggiungi/Elimina Cornice' (Add/Delete Frame) allows user to set up frames by selecting the associated layers. Figure 3 shows the selection of two frames, corresponding to the shelters and the gathering areas layers.

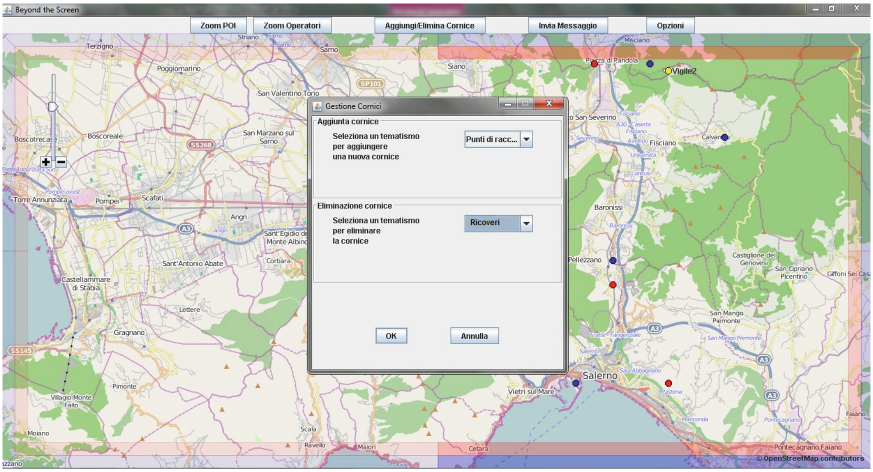


Fig. 3. Setting up frames corresponding to layers 'gathering areas' and 'shelters'.

Figure 4 shows the area of interest associated with a blue frame partitioned into 8 sectors. Data refer to the distribution of shelters and the different coloring of sectors immediately suggests the shelters which are closer. In particular, the up-right frame shows the most intense coloring thus indicating that a greater number of shelters have been set up along that direction.

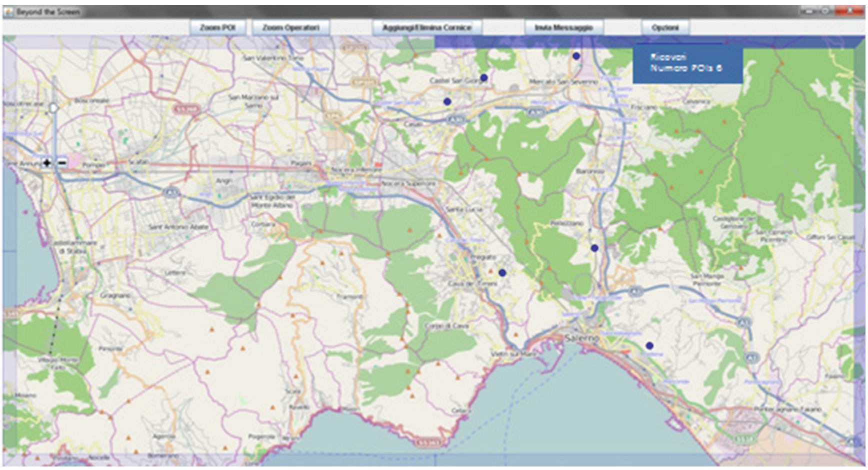


Fig. 4. An overview of a Beyond the Screen scenario

Going back to the scenario:

At 4:25 he receives another request for 33 evacuees from the gathering area no.2 which is associated to the same shelter and he realizes that only 9 beds are left. The GIS operator, who interacts with SIRIO with the support of Beyond the Screen, is asked to search for an alternative shelter. He notices that the frame summarizing information about the shelters (their location and their bed occupancy), has two portions with high color intensity, one on the top and one on the right of the screen. The highest intensity is associated to the top portion, which suggests that the northern shelter is the closest one to the gathering area no. 2 with a sufficient number of beds available. So, the operator is led to pan towards the northern area of the map. There, Gino can verify the situation of the northern shelter no.3, possibly zooming for further details. He discovers that it has still got 48 beds available, so he decides to redirect the 33 people to that shelter. The operator records the new data and notifies the decision to the on-site responders. A new report on the current status of the crisis management process, is distributed to all the local responders.

Figure 5 shows the resulting interface where the zooming level has been automatically set up so as to contain all POIs involved within the area of interest. When clicking on a frame, the name and amount of POIs associated with it are displayed. Besides POIs recalled through these two (blue and red) layers, some additional (yellow) markers are displayed that correspond to the position of on-site teams of responders connected with COC.

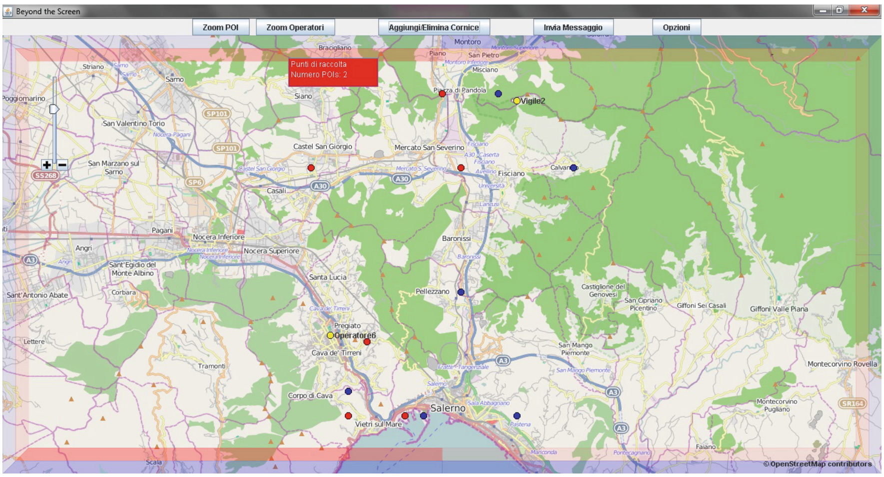
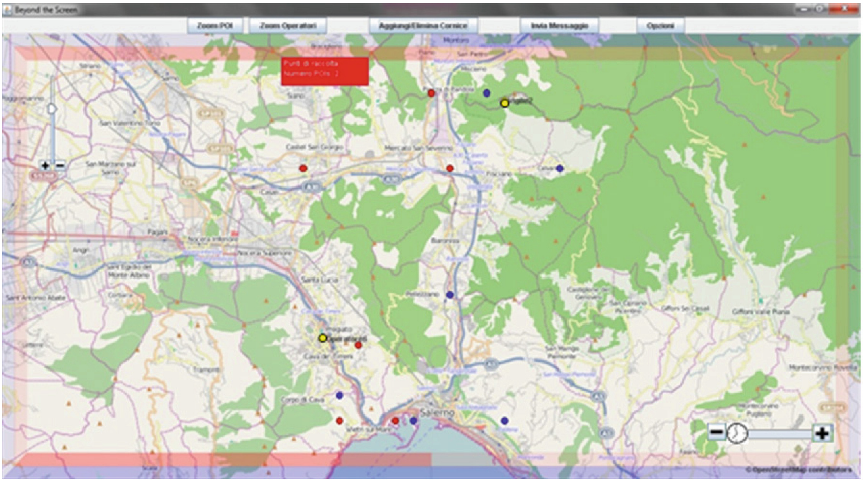
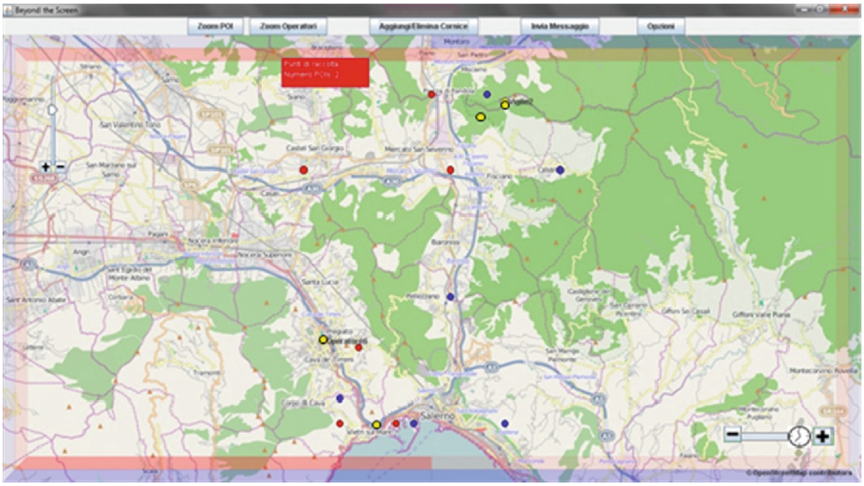


Fig. 5. The resulting overview with two frames and active field workers

In order to allow COC to send information to on-site responders, a message dialog box has been implemented. It is possible to select recipients (one, some, all) and edit the text message.



(a)



(b)

Fig. 6. The time slider on the lower right corner of the map allows decision maker to analyze the evolution over time of an emergency scenario.

The Zoom POI and Zoom Operatori (on-site responders) buttons set the map resolution at such a level that is contains all POIs and responders distributed within an area of interest. Finally, the Option function allows to set up some parameters, such as the size of the buffer zone corresponding to the area associated with the frame(s) and the layers features one wishes to visualize.

At the end of day 1 Gino has a plenary meeting at the COC *to collectively evaluate the evolution of the emergency situation since its beginning and the actions taken so far. By displaying the time slider experts are able to navigate through temporal sequences of the scenario of interest and monitor its evolution. The sequence revels that subsequent requests for evacuation routes originated from gathering area no.1. As a result, Gino and the other attendees agree that one more team of on site responders should be sent to that area as the next action.*

This part of the scenario highlights the innovative feature of *Beyond the Screen*, namely the possibility to navigate through temporal sequences of a scenario thus allowing users to monitor its evolution. Such a functionality is paramount to better understand the effects of past interventions and make an ex-post analysis. Moving backwards the time slider on the interface, the user is able to recognize that the number of teams operating around the gathering area of interest has increased during the last few hours, probably due to the growing number of evacuees who have progressively reached that area (see Fig. 6)

5 Conclusion

Pan & Zoom represents one of the simplest and more used ways to perform analysis tasks on large amounts of information in a map. When decision makers need to monitor a territory to investigate a phenomenon, the width of the area of interest strongly affects the efficacy of his/her activities, independently of the technology available for data visualization. *Beyond the Screen* reduces the usage of repetitive operations by both providing users with hints about data and phenomena distribution around an area under investigation, and allowing a temporal and spatial comparison of evolving scenarios. This is especially important in case of emergency scenarios which evolve differently from what one was expecting and from the devised emergency management plan. In the next few months, the developed server-side application interacting with SIRIO will undergo a usability testing phase with the goal to validate the approach not only in terms of efficiency but also as an effective methodological enhancement of decision making processes.

References

1. Aedo, I., Díaz, P., Carroll, J.M., Convertino, G., Rosson, M.B.: End-user oriented strategies to facilitate multi-organizational adoption of emergency management information systems. J. Inf. Process. Manag. Int. **46**(1), 11–21 (2010)
2. Andrienko, N., Andrienko, G., Jankowski, P.: Map-centred exploratory approach to multiple criteria spatial decision-making. Int. J. Geogr. Inf. Sci. **15**(2), 101–127 (2001)
3. Andrienko, G., Andrienko, N., Bartling, U.: Visual analytics approach to user-controlled evacuation scheduling. Inf. Vis. **7**(1), 89–103 (2008)

4. Doshi, P., Rundensteiner, E., Ward, M., Yang, J., XmdvTool: visual interactive data exploration and trend discovery of high-dimensional data sets. In: Proceedings of ACM SIGMOD 2002 (2002)
5. Ginige, A., Paolino, L., Romano, M., Sebillo, M., Tortora, G., Vitiello, G.: Information sharing among disaster responders - an interactive spreadsheet-based collaboration approach. Comput. Support. Coop. Work (CSCW) **23**(4–6), 547–583 (2014). ISSN 0925-9724
6. OpenStreetMap. www.openstreetmap.org
7. Paolino, L., Sebillo, M., Tortora, G., Vitiello, G.: *Framy* – visualizing spatial query results on mobile interfaces. In: Ware, J., Taylor, G.E. (eds.) W2GIS 2007. LNCS, vol. 4857, pp. 175–186. Springer, Heidelberg (2007). doi:10.1007/978-3-540-76925-5_13
8. Paolino, L., Sebillo, M., Tortora, G., Vitiello, G.: Framy: visualizing geographic data on mobile interfaces. J. Location Based Serv. **2**(3), 236–252 (2008). doi:10.1080/17489720802487949. ISSN 1748–9725, Print/ISSN 1748–9733. Taylor & Francis
9. Paolino, L., Romano, M., Sebillo, M., Vitiello, G.: Supporting the on site emergency management through a visualization technique for mobile devices. J. Location Based Serv. **4**(03–04), 222–239 (2010). doi:10.1080/17489725.2010. Taylor and Francis Group Ltd.
10. Rosson, M.B., Carroll, J.M.: The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications. Lawrence Erlbaum Associates Inc., Mahwah (2002)
11. Sebillo, M., Vitiello, G., Paolino, L., Ginige, A.: Training emergency responders through augmented reality mobile interfaces. Multimedia Tools Appl. **75**, 9609–9622 (2016). doi:10.1007/s11042-015-2955-0. Springer Science + Business Media, New York
12. 3DGis: Sirio (2016). www.3dgis.it. Accessed May 2016