Supporting Decision Making during Emergencies through Information Visualization of Crowdsourcing Emergency Data

Paulo Simões Jr.[1], Pedro O. Raimundo[1], Renato Novais[2,3], Vaninha Vieira[1,3] and Manoel Mendonça[1,3]

[1]*Department of Computer Science, Federal University of Bahia, Av. Adhemar de Barros, Salvador, Brazil*

[2]*Department of Computer Science, Federal Institute of Bahia, Rua Emídio dos Santos, Salvador, Brazil*

[3]*Fraunhofer Project Center for Software and Systems Engineering at UFBA, Av. Paralela, Salvador, Brazil*

Keywords: Emergency Management, Information Visualization, Crowdsourcing, Decision Support.

Abstract: Decision making during an emergency response requires having the right information provided in the right way to the right people. Relevant information about an emergency can be provided by several sources, including the crowd at the place where the emergency is happening. A big challenge is how to avoid overwhelming the decision makers with unnecessary or redundant information provided by the crowd. Our hypothesis is that appropriate information visualization techniques improve the understanding of information sent by a crowd during an emergency. This work presents an approach for emergency information visualization, gathered through crowdsourcing, which improves context-aware decision making by keeping a real-time emergency state board. This approach was implemented in ERTK, as a proof of concept, and evaluated with 15 emergency management experts in Brazil. The yielded results show that our approach has the potential to assist a context-aware decision making during an emergency response.

1 INTRODUCTION

According to the United Nations Department of Humanitarian Affairs (DHA, 1992), an emergency is "a sudden and usually unforeseen event that calls for immediate measures to minimize its adverse consequences". These can be natural events (e.g. earthquakes, tsunamis) or men-made (e.g. terrorist attacks, stampedes, mass shootings) and their consequences may be a disaster for life, environment and facilities.

The emergency management cycle has four different stages, aligned with the timeline of the emergency: preparedness, response, recovery and mitigation(Horita et al., 2013; Poser and Dransch, 2010). The response phase is the most critical one, and involves several activities related to decision making, rescuing and combat, intended to save lives and deal with the emergency consequences in the fastest possible way (Waugh and Streib, 2006; Lanfranchi et al., 2013). During the response phase, emergency managers need accurate and reliable information to support their decisions. A late or inaccurate decision may result in damage to human life and hinder the overall emergency management process (Thompson et al., 2006).

Crowdsourcing aims to use a crowd to do a set of tasks that would otherwise be performed by a smaller number of people (Howe, 2006). This technique has been used to support emergency management and their utility has been ratified in real emergency scenarios, as is the case of the Ushahidi platform (Heinzelman and Waters, 2010; Duc et al., 2014). People in the place of an incident often have the most updated information regarding the emergency, and are able to provide what the emergency managers need to support their decision-making (Gao et al., 2011).

We developed a crowdsourcing-based emergency management platform called RESCUER which aims to support command and control centers on acquiring and processing context-aware multimedia information about an emergency, using the crowd as the main information source. However, a challenge is how to avoid overwhelming the decision makers with inappropriate, inaccurate, outdated, or redundant information coming from the crowd (Gao et al., 2011), which can impair their decisions. Several information visualization (Mazza, 2009; Ware, 2012) (InfoVis) techniques have been used to improve the presentation of emergency information to decision makers (Dusse et al., 2016; Wu et al., 2011; Besaleva and Weaver, 2013).

A recent systematic mapping study (Dusse et al.,

Jr., P., Raimundo, P., Novais, R., Vieira, V. and Mendonça, M.
Supporting Decision Making during Emergencies through Information Visualization of Crowdsourcing Emergency Data.
DOI: 10.5220/0006370701780185
In *Proceedings of the 19th International Conference on Enterprise Information Systems (ICEIS 2017) - Volume 3*, pages 178-185
ISBN: 978-989-758-249-3

2016) shows that social networks (e.g. Twitter, Facebook) are the main tool for acquiring crowdsourcing information in emergency management. This study also shows that most tools using InfoVis apply similar techniques, which consists of devising a set of icons or shapes to represent the information on a map.

In our research, we argue that decision making in emergency response may be improved by focusing on presenting the most relevant information about the emergency to the emergency managers. In our approach, we employed several heuristics to summarize gathered information, using icons and text-based visual metaphors. We also incorporated different charts detailing the distribution of crowdsourcing information, which the emergency manager can use to refine his/her judgment about the emergency.

To evaluate our InfoVis approach, we implemented a proof of concept tool called Emergency Response Toolkit (ERTK), a component of RESCUER platform aimed to support command and control centers on analyzing information from the crowd. We also conducted a case study with 15 experts in emergency management to gather their impressions and feedback on the proposed approach. The results indicate that our approach has the potential to improve decision making in emergency management.

The rest of this paper is organized as follows. Section 2 discusses related works about the use of InfoVis in the emergency management. Section 3 presents our visualization approach. Section 4 describes the design and and execution of our evaluation. Section 5 presents our experimental findings. Finally, we draw our conclusions and indicate future directions of research in Section 6.

2 RELATED WORK

The visualization of crowd data faces several unique challenges due to the nature, the amount and the format of data involved (Gao et al., 2011). The visualization tool has to allow the user to gather an overall view of the data, and also be able to drill down and look into specific data points (Dusse et al., 2016). Crowd data must also usually be categorized and transformed into useful information for decision making. In this section, we will discuss existing tools and approaches to visualize crowd data in emergency management, their achievements and shortcomings.

Ushahidi is an open-source platform that has been used in several high-profile disasters such as the Haiti earthquake. This platform provides tools for users to load, filter and visualize crowd data from multiple sources (email, twitter, SMS *et cetera*) (Heinzelman and Waters, 2010; Duc et al., 2014). Data that arrives from the available channels are gathered if they contain one or several of predefined keywords. Additionally, Ushahidi provides a web-based form and a mobile app that users can utilize to input structured data in the system.

The main visualization component of the Ushahidi platform is an annotated map. This map allows users to obtain a generalized view of the emergency and clusters reports based on the level of zooming of the map and their proximity. There is also a timeline of the emergency and widgets that allow the user to filter the reports by category, area and time. The clustering strategy adopted by Ushahidi provides an adequate view of which areas need more attention (i.e., have more people). But sometimes results in undesirable clutter and occlusion of informational elements.

Sahana Eden (Duc et al., 2014) is another prominent open-source emergency management tool that has been successfully deployed in the Haiti earthquake of 2010. Sahana Eden focuses on the preparedness and mitigation phases of emergency management and has a plethora of features to organize and manage emergency management assets (human and otherwise) whose investigation are beyond the scope of this paper.

Despite being used to display static information, the map provided by Sahana Eden has filtering and visualization categories. Nevertheless, both Sahana Eden and Ushahidi lack the ability to represent what is happening as anything more than points, as highlighted by Duc *et al.* (2014) .

Another platform to deal with crowdsourcing data is presented by Wu *et al.* (2011), with focus on participatory multimedia generation. This platform consists of a mobile application that sends geo-tagged pictures to a server, a web-based desktop application (called CIVIL) that allows the emergency management professionals to view the received information, and server infrastructure (Wu et al., 2011).

CIVIL displays the pictures received from the users in real-time as thumbnails on a map. The thumbnails can be interacted with, allowing the user to contact the sender of the picture. The desktop interface of the CIVIL application provides: “a private map, a public map, and a set of analysis tools to support collaboration and decision making” (Wu et al., 2011). Each user can make annotations and sketches on his private map or the public map, which is shared across all users. The analysis tools provided by CIVIL include “a chatting panel, a table sorting all annotations, a chart showing accumulated annotations, and a timeline visualizing individual annotation activities” (Wu et al., 2011). CIVIL also tracks the location of the users sending pictures.

The map utilized in CIVIL has more features than the ones presented this far, as it supports annotations and different visualization modes. However, it displays the individual pictures to the user, and thus will generate more clutter and noise as more people use the mobile application.

CrowdHelp (Besaleva and Weaver, 2013) is another existing tool to deal with crowdsourcing information in emergency management. Using this tool, mobile users are able to provide information about the event, their physical condition and symptoms. The system uses this information to facilitate medical triage and provides visualizations for emergency management professionals through a web interface, in real-time.

CrowdHelp provides several ways to cluster the information. Giving users full control over the machine learning algorithms utilized for clusterization. In terms of visualization, however, these clusters are displayed as data points with different colors. Color is a sub-par visual attribute to represent the clustering of information because it does not remove any of the clutter and clashes with the geographical view, which induces a proximity-based clustering metaphor.

As shown so far, most InfoVis solutions applied to emergency management focus on map-based visualizations of the collected information which differ mainly in the specific format, clusterization approach and associated data of the points displayed on the map. Some of the tools presented here also provide non map-based visualizations; however, these are just plain tabular displays of the gathered data. Map-based visualizations of georeferenced data are staple in emergency management systems; therefore, we implemented our approach to this kind of visualization attempting to minimize noise and occlusion.

However, the main appeal of this work is that we proposed, implemented and evaluated (Section 4) a novel way to provide a summary of crowdsourced data to the user, utilizing icons, text, and several custom widgets. This approach differs slightly from existing work, but shows promise, as we highlight in Section 5. In the next section, we elaborate on how ERTK deals with the visualization of crowdsourcing information and the aspects of our approach.

3 AN APPROACH FOR INFOVIS IN EMERGENCY RESPONSE

Our research set out to identify proper ways to present crowdsourcing emergency data so that emergency managers can quickly identify the most relevant set

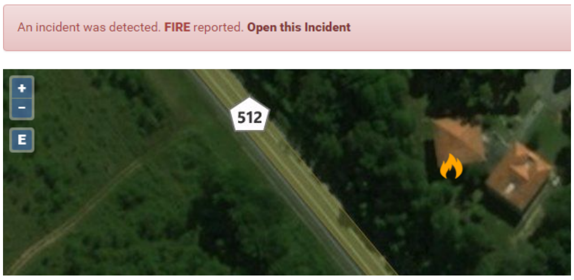

Figure 1: Example of the new incident alert for when a fire incident is detected by the system.

of information during the emergency response. Based on workshops conducted with emergency management specialists from Brazil and Europe, and feedback received during during the evaluation of our first efforts (Simões Júnior et al., 2015), we focused on three specific needs of emergency managers: to identify the type of incident and where it is happening, to know the available information for the incident at all times; and to know how reliable a given information is.

To allow users to identify where the emergency is happening we use a map view together with an iconographic representation of the incident type. This combination (map and icons) allows the emergency managers to quickly establish the place of incident, and what is happening. Additionally, we display a visual alert with a message describing what is the type of the incident, to counteract the possible misinterpretation of the icons by some users. Figure 1 shows a situation where a emergency with fire incident is happening, presenting the fire icon (middle-right) and the incident alert (top, red frame).

The Incident Detail View is the main view of our approach. Figure 3 presents this view, which lets the emergency managers quickly identify what is happening at the incident site, based on the information sent by the crowd. This view can be subdivided in 5 areas: (1) an interactive timeline that shows and can be used to alter the incident status; (2)the aggregation results of the crowdsourcing data; (3) a multimedia carousel that shows the images and videos sent by the crowd, with an area that highlights the current selected media; (4) a map that shows the most relevant reports within the incident area (e.g. civilian reports within the hot zone, workforce reports); (5) and a header containing the incident ID and its type.

The **Aggregated Incident Data** is the main contribution of the incident detail view. It presents the most relevant data for each information collected from the crowd. By applying a set of heuristics to each report received, we identify the most relevant data for a given information at an specific time (e.g. the current number of injured, the environmental damages). These results are then expressed using icons and text, as shown in Figure 2. The labels of each information (e.g. Number of Injured People, Environmental Damage) are given a color that indicates the most reliable profile that confirms the data being shown. We use the red color to represent civilians, orange for supporting forces and green for workforces.

Figure 2: Aggregated information from civilians (top left), supporting forces (bottom) and workforces (top right).

To make the emergency managers aware that the value of an information changed, we highlight the representation of that information with every change. We consider an information as "changed" when a more reliable profile confirms that information, and/or when the most relevant data for the information changes (e.g an increase in the number of injured, a change in the color of the smoke). Figure 2 shows the highlighted state for the information "Environmental Damages". To ensure that the changes were acknowledged, the highlight only disappears after the emergency manager interacts with it.

We expected that these set of features could help emergency managers to quickly identify the most relevant information provided by the crowd during the emergency response phase. To evaluate if emergency managers could understand and use these features, and ultimately if they would help them in the decision making process, we planned and executed a case study described in the next section.

3.1 Implementing the InfoVis approach in ERTK

We implemented the described visualizations in the ERTK module of the RESCUER project to evaluate our approach. Emergency managers will be able to use it during the emergency response phase in large-scale events or industrial parks.

ERTK is a web application with many features designed to help in emergency management tasks (e.g. map annotation, alerts, messages broadcast). Among these, we implemented the proposed visualizations to allow quick identification of the type of incident, where it is happening, which emergency information is available and the reliability of the information.

From our planning, the users would see the incident alert, apprehend the type of incident that happened, click on the incident alert link to go to the incident detail view, obtain the knowledge about the current available information and accompany the evolution of the incident though the update feature. The displayed information and its reliability level would aid the decision making of the emergency managers.

4 EXPERIMENTAL EVALUATION

This section describes the experimental evaluation we conducted in order to evaluate ERTK.

4.1 Evaluation Tasks

We created an emergency scenario where the evaluation participants would perform a set of tasks. In this scenario, an explosion happened during a large-scale event and the people in the crowd started to send reports through the RESCUER mobile app. The participants would play the role of a C&CC operator and would try to complete the tasks present at Table 1. For each task, we expected the participants to use a specific visualization feature.

The proposed tasks are the result of interviews with emergency management experts, and reflect what they would try to do, in the proposed scenario, using ERTK. The feature column shows which visualization feature we expected the participants to use to complete each task.

In tasks T1 and T2 we wanted to know if the new incident alert, and the iconographic incident representation in the map, provided the participants with a clear view of what type of incident was detected and where it started. We also evaluated if the participant could easily understand how to access the detailed incident information.

With T3 we sought to see if the participants were able to identify all available information of the incident, and outline what aspects of the visualization they would notice and those they would not (e.g. if they would perceive the colors in the title, the incident status, the highlights, etc.).

Through T4, we aimed to evaluate if the participants would perceive the incident status timeline not only as an information source but as an interactive widget as well.

From T5, we wanted to confirm if the information highlight would clearly indicate a change in the available data. This is directly related to T7, were we provoked a change in the title colors of some information, and also changed the pictures being shown. We wanted to see if the participants noticed these changes and, in case they had passed the mouse over updated

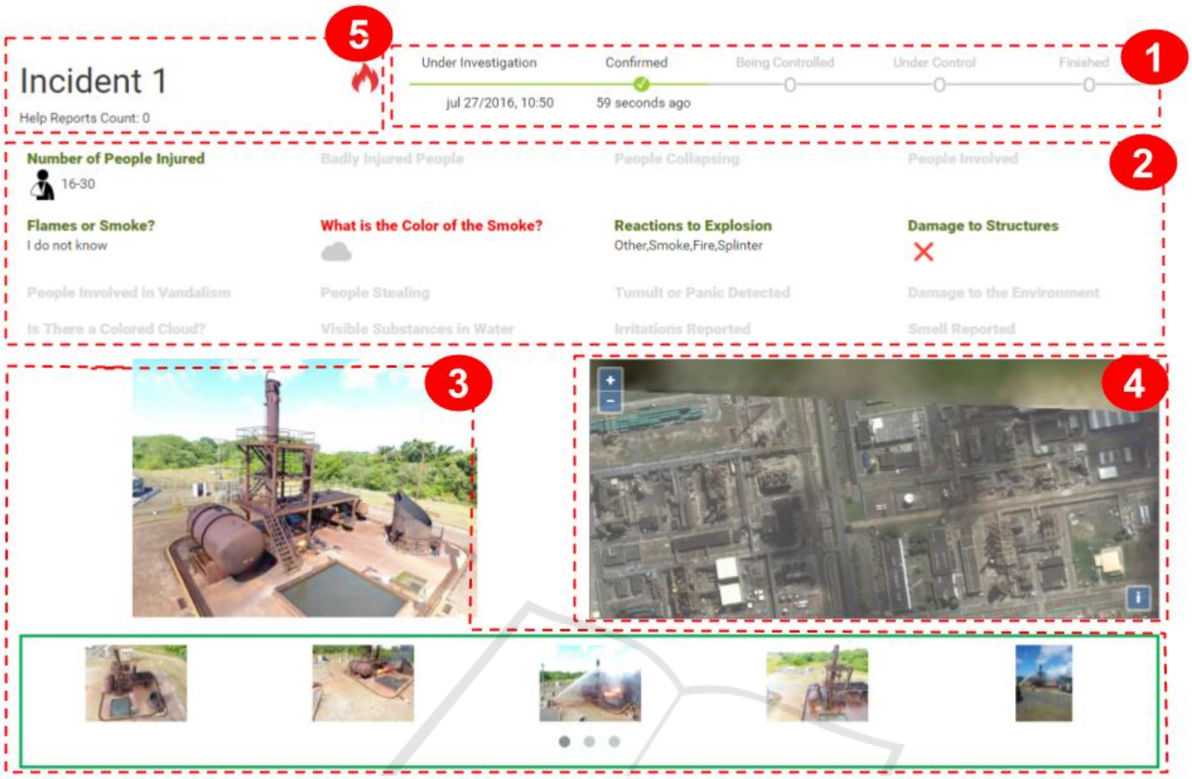

Figure 3: Incident Detail View showing: the Incident Status Timeline (1); the Aggregated Incident Data (2); the Incident Media (3); the Incident Map (4); the Incident Id and Type (5).

information, we wanted to see if they would indicate that the information changed again.

On T6 the system would be in a state in which the aggregated information would be indicating a smoke color (e.g. dark grey) and a image with a different smoke color (e.g. white grey) would be in the images carousel . We wanted to see if the participants would give more importance to the image or to the aggregated information.

Finally, we expected the participants to notice the different colors in the information titles, but we did not predict that they would associate it to different sender profiles (e.g. civilian, workforces) without training. With T8, we wanted to confirm if the color/profile relationships we used, namely: red for civilians; orange for supporting forces; and green for workforces matched the participants' view.

4.2 Evaluation Design

A researcher accompanied the participants during the tasks, telling them when to start a task, taking notes about the participants' remarks and helping then in case they expressed any doubts.

We did not set time limits for any of the tasks and did not train any participants either. We wanted to observe if they could perceive and use the features we described in section 3 without previous knowledge about the system and, if they could not, which other features they would use. To compensate the lack of training we informed the participants that they could skip tasks. We decided to execute the evaluation procedure with one participant at time, and to record the computer screen and participants remarks during the whole process.

We prepared three sets of reports that would alter the system state during the duration of one or more tasks. Two researchers were responsible for feeding the data to the system at specific times, thus, we would be able to compare if the information provided by the participants while answering the tasks was complete (e.g. if they were able to list all available information or the changes that occurred). These sets could be sent manually, using the RESCUER mobile app, or through a program we created. The two auxiliary researchers would be in contact with the evaluator researcher during the whole experiment. The evaluator would tell the auxiliaries the moment to send the report sets. Figure 4 displays the general workflow of our evaluation.

Table 1: Evaluation tasks and expected visualization features to solve them.

ID	TASK	VISUALIZATION FEATURE
T1	Identify the type of incident that happened and where it happened	Incident alert, incident icon on Map
T2	Find the screen with information about the incident	Incident alert
T3	List all available information about the incident	Incident status timeline, aggregated incident data, incident media carousel
T4	Change the incident status to confirmed	Incident status timeline
T5	In case you identify any, list the changes in the information regarding the incident	Highlighted information
T6	Identify the color of the smoke	Incident media carousel, aggregated incident data
T7	Again, in case you identify any, list the changes in the information regarding the incident	Incident media carousel, aggregated incident data
T8	Colors indicate the profile of the user who sent an information (i.e. civilian, supporting force, workforce). According to your feelings, associate a color to each user profile	Color from the title of aggregated incident data

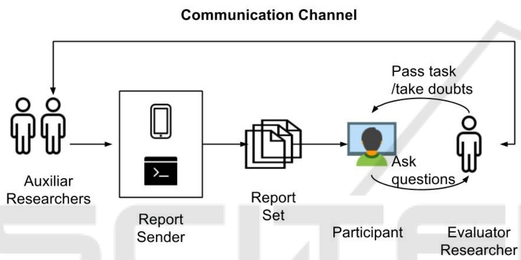

Figure 4: Evaluation Procedure Dynamic.

After all tasks were completed, we asked the participants to answer a feedback questionnaire and fill in a characterization form.

4.3 Evaluation Execution

We performed the evaluation at the International Congress of Mass Disaster (CIDEM 2016) and at the Command Center of Porto Alegre (CEIC[1]).

In both places, all participants were randomly selected. A criteria to participate in the evaluation was to be a member of an organization that would perform emergency response activities (regardless of the emergency type). To encourage the candidates participation we offered them to be part of a 32 GB thumb drive raffle.

We gave the chosen participants an overview of RESCUER purpose and explained that we wanted them to use ERTK to execute some tasks and give us feedback at the end. We told each of them that there were no right or wrong answers, and that they could skip any task if they wanted to. They were free to use the system as they wanted. When they accepted the conditions, we applied the evaluation as we had planned.

[1]http://www.portoalegre.rs.gov.br/ceic

5 RESULTS AND DISCUSSION

We had a total of fifteen participants, six on CIDEM and nine at CEIC. Their time of experience with emergency situations ranged from a few months to 40 years. Their roles and the organization they belonged to greatly varied: police, firefighters and civil defense are some examples. Also, all CIDEM participants declared not having previous experience with emergency management systems, which was the opposite for the CEIC participants.

The participants took an average of one minute to complete each task, counting the time they spent giving us feedback about their feelings while doing each task (e.g. they explained us what they were thinking, why they made some decisions). The feedback gathered from the evaluation in the form of the applied questionnaire, the participants feedback during the evaluation and by observing the way, which they interacted with the visualizations, is very encouraging.

Only one participant considered the system as useless to help in emergency management tasks. He could not identify the meaning of most icons and the system responses to his actions were not as he expected. His feedback was that the system should be clearer in the messages it was passing. We found this most useful, while most of the other participants did not had the same difficulties, we could identify interesting points in his interaction with the system, and

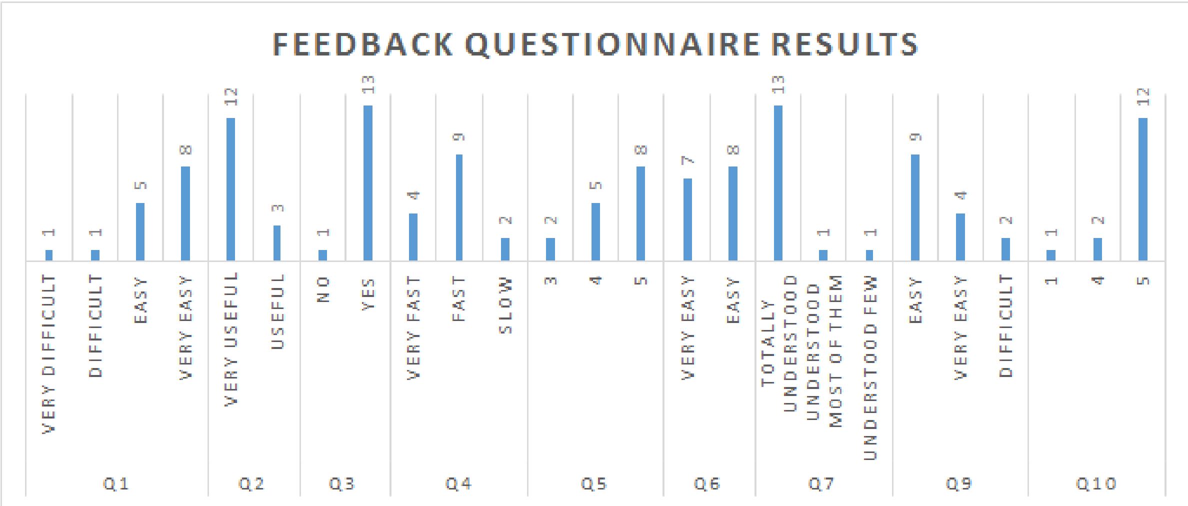

Figure 5: Results of the feedback form given by the evaluation participants. One participant did not answer Q3.

his expectations, that can help us to improve the visualization mechanisms applied.

Overall, the participants identified the type of incident and the place where it was happening using either the map or the **new incident alert**, as we were expecting. In general, most systems related to emergency management support work with maps and icons, which allow for quickly identification that ”something is happening at this place”. We observed that the participant that considered this task **very difficult**, was able to complete it in 10s. While the one who considered it **difficult** is the same one that deemed the system useless. While we are certain that there is room for improvement, based on the overall feedback received, we consider the provided features for helping in identifying the place and type of incident show great promise.

”Finding the screen with information about the incident” (Task T2) was the task that the participants took more time to complete as the majority of them did not notice, or did not understood, the link in the **incident alert**. Those who did not use the link, either skipped the task (two of them) or followed almost the same steps to complete it (using tabs within ERTK interface). This shows that there needs to be a better indication that there is a link within the alert or that other interaction mechanisms should be used to take the users to the **incident detail view**.

All participants correctly identified the information we were expecting with tasks T3, T5 and T7. The results of these tasks were very important for us, because they showed that the participants perceived the information we were expecting using the features we expected them to use. The participants were able to tell which information was available. They perceived when those information changed and which were the changes. This result is aligned with our efforts to shift the focus from the traditional map and iconographic visualizations present in most emergency management system to an approach focused on the aggregation of information gathered through crowdsourcing.

The answers of the feedback questionnaire[2,3] were mostly positive (Figure 5), and supported the insights we have while observing the participants using ERTK. The majority of them considered to be fast in finding the information about the incident. They were also able to understand the icons we used in the visualizations and found to be easy to perceive when an information changed. Most important, 12 participants deemed the system as **very useful** regarding the possibility of being of help on supporting decision making during an emergency.

6 CONCLUSION

The people present in the site where an emergency is happening are an invaluable source of information for emergency managers. However, they need support to help them make sense of all information available.

Current emergency management systems that make use of crowdsourcing data, often use maps and icons to present the collected data. While this have been proven helpful, we believe that a visualization focused on the results of an aggregation of the crowdsourced data that can improve the way emergency

[2] accessible at https://goo.gl/Ym1Gaa

[3] One of the participants did not answer Q3, hence the sum for this question is less than the number of participants

managers make sense of it.

In this paper we presented an InfoVis approach to visualize the emergency data gathered through crowdsourcing. We implemented this approach in ERTK, whose goal is to allow emergency managers to quickly identify the relevant information about an emergency during the response phase, supporting their decision making process.

We designed and ran an evaluation with fifteen emergency specialists to understand if and how they perceived perceive and interacted with the proposed visualizations. The results of this evaluation were ultimately positive, highlighting the strengths of the approach and highlighting several points of improvement within the proposed visualizations. Most of the participants said that the approach proposed here would be helpful in supporting decision making during the emergency response.

Future directions for this work include: improving our approach based on the received feedback, devising new interaction mechanisms, proposing visualizations that better support the visualization of contradictory information that arrives from a crowd.

ACKNOWLEDGEMENTS

This work was supported by the RESCUER project, funded by the CNPq/MCTI (Grant: 490084/2013-3) and by European Commission (Grant: 614154). We thank all researchers that participate in the RESCUER project for their valuable work. We also thank the commander of CEIC - POA and the organizers of CIDEM for allowing us to perform our evaluations.

REFERENCES

Besaleva, L. I. and Weaver, A. C. (2013). Crowdhelp: A crowdsourcing application for improving disaster management. In *Global Humanitarian Technology Conference (GHTC), 2013 IEEE*, pages 185–190. IEEE.

DHA, U. (1992). Internationally agreed glossary of basic terms related to disaster management. *UN DHA (United Nations Department of Humanitarian Affairs), Geneva*.

Duc, K. N., Vu, T.-T., and Ban, Y. (2014). Ushahidi and sahana eden open-source platforms to assist disaster relief: Geospatial components and capabilities. In *Geoinformation for Informed Decisions*, pages 163–174. Springer.

Dusse, F., Júnior, P. S., Alves, A. T., Novais, R., Vieira, V., and Mendonça, M. (2016). Information visualization for emergency management: A systematic mapping study. *Expert Systems with Applications*, pages 424–437.

Gao, H., Barbier, G., Goolsby, R., and Zeng, D. (2011). Harnessing the crowdsourcing power of social media for disaster relief. Technical report, DTIC Document.

Heinzelman, J. and Waters, C. (2010). *Crowdsourcing crisis information in disaster-affected Haiti*. US Institute of Peace.

Horita, F. E. A., Degrossi, L. C., de Assis, L. F. G., Zipf, A., and de Albuquerque, J. P. (2013). The use of volunteered geographic information (vgi) and crowdsourcing in disaster management: a systematic literature review.

Howe, J. (2006). The rise of crowdsourcing. *Wired magazine*, 14(6):1–4.

Lanfranchi, V., Mazumdar, S., and Ciravegna, F. (2013). Evaluating the real usability of a c2 system–short and controlled vs long and real. *Proceedings of ISCRAM 2013*, pages 62–66.

Mazza, R. (2009). *Introduction to information visualization*. Springer Science & Business Media.

Poser, K. and Dransch, D. (2010). Volunteered geographic information for disaster management with application to rapid flood damage estimation. *Geomatica*, 64(1):89–98.

Simões Júnior, P., Novais, R., Santos, V. V., Pedraza, L. G., Mendona Neto, M. G., and Lima, K. V. C. (2015). Visualization mechanisms for crowdsourcing information in emergency coordination. In *XIV Brazilian Symposium on Human Factors in Computer Systems, 2015, Salvador*.

Thompson, S., Altay, N., Green III, W. G., and Lapetina, J. (2006). Improving disaster response efforts with decision support systems. *International Journal of Emergency Management*, 3(4):250–263.

Ware, C. (2012). *Information visualization: perception for design*. Elsevier.

Waugh, W. L. and Streib, G. (2006). Collaboration and leadership for effective emergency management. *Public administration review*, 66(s1):131–140.

Wu, A., Yan, X., and Zhang, X. L. (2011). Geo-tagged mobile photo sharing in collaborative emergency management. In *Proceedings of the 2011 Visual Information Communication-International Symposium*, page 7. ACM.