Investigating the Use of Visual Analytics to Support Decision-Making in Crisis Management: A Multi-Method Approach

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ABSTRACT

People working in a crisis are generally under stress while having to make the right decisions at the right time. They have to process large amount of data as well as assimilate the received information in an intuitive way. Like Crisis Management (CM) itself, Visual Analytics (VA) is a multi-disciplinary research area and is potentially useful to analyze and understand the huge amount of multidimensional data produced in a crisis. Our work investigates how researchers and practitioners are using VA in decision-making in CM. We aim to develop a computational reference model based on VA. For that, we carried out a multi-method approach to collect and analyze CM data. This paper presents our multi-method investigation on the use of VA in CM context. It firstly reports on a systematic mapping study to analyze the available information visualization tools and their applications in CM. To complement this information, we report on questionnaires and ethnographic studies applied during the large events held in Brazil in recent years. Then, we analyze existing tools for visualizing crisis information. Lastly, we analyze the data gathered from interviews with six professional crisis managers. The compiled results show that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We consider that further research into the application of VA is required to improve decision-making processes in CM.

Keywords

Crisis Management, Decision-Making, Visual Analytics, Data Collection Methods.

INTRODUCTION

Crises have very complex and dynamic contexts where the response process should suit unforeseen situations without causing social harm or jeopardizing people's lives (ESRI, 2009). Examples of crises that greatly stimulated research interest in this area were the attacks of September 11, 2001 (Schmemann, 2001) and Hurricane Katrina in 2005 (Waugh and Streib, 2006), both in the United States. More recently, the Hurricanes Harvey, Irma and Maria (CNN, 2017) and a sequence of terrorist attacks in European cities (Bloomberg, 2017), mass shootings in U.S. (CNN, 2018) among others have reinforced this. Crisis management (CM) refers to the ability to deal with crisis tasks in all their phases and iterations. In general, this is done by multiple government agencies which do not work together routinely. These agencies usually use the doctrine of Command and Control (C2) to help in the coordination of activities (Turoff et al., 2004).

CM varies because the context, events and information are never the same from one crisis to another. Each

management task requires many different types of information about the incident from several sources (Turoff et al., 2004), such as information systems, external proprietary databases, resources in the field, Internet of Things sensors, social media and other open source media. Nowadays, C2s are equipped with breakthrough technologies, especially visual systems, such as the latest generation mobiles, tabletops, e-caves and video walls (Duse et al., 2004). This union of data sources and novel technologies provides C2 with a huge amount and of information of great heterogeneity.

Decision making during a crisis requires having the right information, provided in the right way, to the right people, at the right time. While crisis managers working in a crisis are generally under stress, they have to make effective decisions with agility. Having reliable and up to date information is essential in order to help in making decisions (Yates and Paquette, 2011). Crisis managers need to assimilate the received information in an intuitive way and the information needs to be adaptable in the context of the current crisis. In addition, if the information is not presented in effective ways, it can be hard to analyze it, or in the worst cases, it can be misinterpreted. Literature shows that suitable information visualization techniques improve the understanding of crisis information (Dusse et al., 2016).

Recently, researchers have been using Visual Analytics (VA) to support understanding in this subject (Andrienko et al., 2007; Tomaszewski and MacEachren, 2012; Chae et al., 2014;). VA is potentially useful for analyzing and understanding the huge amount of multidimensional information produced in a crisis (Keim et al., 2008). The benefits brought by VA to the analysis of crisis information also come along with certain challenges. These include: (1) how to map VA concepts with the countless variables of a crisis to support the managers in quickly identifying reliable information to make decisions; (2) whether researchers and practitioners are using VA techniques and tools effectively to tackle challenge 1; and, (3) how to enhance VA applications with minimal impact on current CM activities. This paper reports our initial steps to address these challenges.

The objective of this paper is to investigate the use of VA in CM context using a multi-method approach carried out in long-term studies. We collected and analyzed data from the literature through a systematic mapping study and *in-vivo* studies such as two ethnographies, questionnaires and a survey (interview) protocol. These investigations are the initial part of a broader work that aims to define a computational reference model. The main objective of this model is to use VA to enhance decision-making in CM. The research question of the broader work is “What aspects of Visual Analytics are under-exploited in supporting decision-making in Crisis Management?” The data collection and analysis reported in this paper are geared to answer this question.

We found that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We expect that extending research and the application of VA techniques and tools in CM will have a positive effect on the area.

The rest of the paper is presented as follows. In the following section, we provide a theoretical background followed by a brief discussion of our research approach. We then present our data collection and analyze our findings. In closing, we suggest future research directions to enhance VA to support decision-making for CM.

BACKGROUND AND RELATED WORKS

Crisis policymakers recommend the use of local-based information (e.g. demographic density, building materials, city structures); the use of social technologies (e.g. social media, crowdsourcing); and hazard-monitoring systems (e.g. satellite remote sensing, climate sensors, suspected terrorists) for crisis risk reduction (Horita et al., 2013; Turoff et al., 2004). These, in turn, increase the volume and heterogeneity of the available information, causing problems in the completeness and timely analysis of this information. We identified some works in the literature that address these problems by using VA in their approaches (Andrienko et al., 2007; Tomaszewski and MacEachren, 2012; Chae et al., 2014).

VA is more than just information visualization. It is the science of analytical reasoning facilitated by highly interactive visual interfaces. It can be seen rather as an integral approach to decision-making, combining visualization, human behaviors and data management (Keim et al., 2008). Recently, Keim et al., (2008) adjusted Shneiderman’s mantra[1] to VA context: “Analyze first, Show the Important, Zoom, Filter and Analyze further, Details on demand”. In other words, this extended mantra is calling for an astute combination of analyticals

[1] "Overview first, Filter and Zoom, Details on demand" (Shneiderman, 1996)

approaches together with advanced visualization techniques (Keim et al., 2008). In Andrienko et al., 2007, the authors designed a suite of tools to support transportation-planning tasks such as crisis evacuation. The transportation schedule is a complex construct involving heterogeneous objects with states and positions varying in time. The tools used genetic algorithm with VA techniques such as interactive visual interfaces. In Tomaszewski and MacEachren (2012), the authors present visual interfaces to construct and represent geographical and historical context in CM and humanitarian relief. They implemented geovisual analytics tools that supports document foraging and sense making to construct the geo-historical context. In Chae et al. (2014), the authors analyze social media data, with an interactive spatiotemporal VA and spatial decision support environment to assist in evacuation planning. They demonstrated how to improve investigation by analyzing the extracted public behavior responses from social media before, during and after natural crisis. Their approach focuses on identifying the whereabouts and movements of people in order to understand mass behavior.

Analyzing the state-of-the-art, we concluded that the current works lack context-sensitive approaches. Moreover, the visualizations fail to use multiple data sources and, in general, the visualizations are used for a specific activity, e.g. evacuation plan, humanitarian relief. Given the research gap, our goal at the moment is to collect data from the literature and the CM environment to understand and to propose solutions in the visualization and analysis of crisis information.

Some works gave us insights on how to collect data in this research area. Horita et al. (2013) and Mirbabaie et al. (2016) carried out systematic literature reviews, both about volunteered geographic information and crowdsourcing in CM. The former work focuses on which crisis phases and crisis types the primary studies use voluntary information. The latter addresses quality assessment elements that are used in the studies, as well as the methods that are employed to measure these elements. In Gralla et al. (2015), the authors held a workshop with experienced specialists to understand the information requirements of humanitarian responders to sudden onset crises. Simões et al. (2015) were in the Rescuer Project (Villela et al., 2014), which develops a solution to support command centers in quickly managing crisis based on crowdsourcing information focusing on incidents in industrial areas and at large-scale events; the authors held workshops with specialists in crisis response and their intentions were twofold: to validate the preliminary visualizations and to improve them based on the received feedback. Horita et al. (2016) conducted participatory observations and interviews with practitioners from a C2 that monitors imminent natural crisis, mainly floods; the authors collected data so as to understand the activities required in the decision-making process of early warning systems.

It is clear from the literature that most works are highly context-specific, e.g. industrial areas, large events or floods. The state-of-the-art may derive general principles of information requirements, but the literature provides a limited basis for doing so at this point. As a result, in order to drive the development of visualization tools, researchers are analyzing the information needs within a limited scope and in specific CM contexts. However, the C2 practitioner's routine requires a multi-context visualization approach because they deal with crises regardless of cause, size, location, or complexity.

Very little work of this type has focused on a given CM. A critical step is to ask those who manage crisis what information they actually use, how visualizations are presented to guide their decisions and how system developers can improve this. Hence, we collect and analyze data from the literature and *in-vivo* studies through a multi-method approach. The present study takes initial steps to fill this gap by linking VA for the decision-making needs of crisis managers.

METHODS

Our multi-method approach followed three stages: the planning of the scope of work (Stage I), the data collection itself (Stage II) and the data analysis in depth (Stage III). Figure 1 shows the research approach that we detail in this Section.

This paper is **part** of a bigger research work. We are carrying out an *in-vivo* study, immersing ourselves in the day-to-day of CM activities in the Intelligence and Operation Center (COI) (SSP-BA, 2016), which is a branch of the Public Security Secretary of the state of Bahia. COI was created in 2016, taking the place of the Regional Command and Control Integrating Center of the state of Bahia (CICCR-BA). Previously in 2011, the Federal Government of Brazil created the Extraordinary Secretary of Security for Large Events (SESGE), which is a branch of the Brazilian Ministry of Justice. The main purpose of SESGE is to coordinate the activities of the agencies involved in public security and civil defense during the large events that have taken place in Brazil in

recent years (SESGE, 2012). In 2013, SESGE se up C2s, in headquarters cities of large events. The old CICCR-BA was one of these. In these centers, multi-agencies work together in coordination and sharing resources.

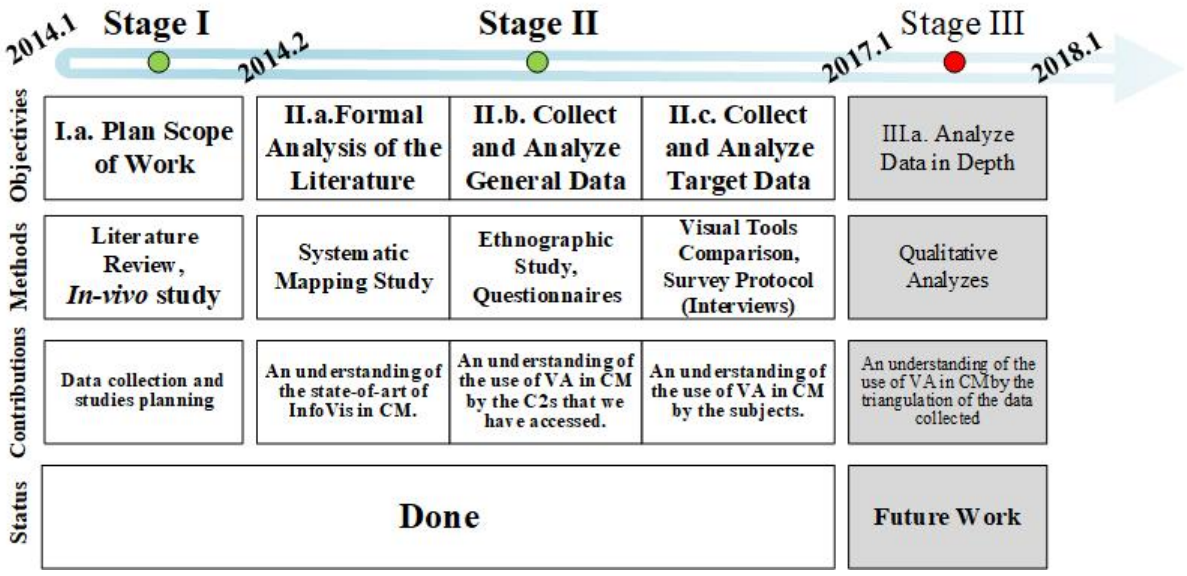

Figure 1: Multi-Method Approach

We also visited others Brazilian C2s and one in Europe. During Stage II, we visited the Regional Command and Control Integrating Center of the state of Rio de Janeiro (CICCR-RJ), the National Command and Control Integrating Center of Brazil (CICCN-DF), Command Integration Center of the City of Porto Alegre (CEIC), Defense Zone of the Paris Police Prefecture (DZPPP), among others. Visiting other C2s was very useful to compare and map similarities and inconsistencies among them.

Although COI has its own resources, the center works in collaboration with several institutions such as other CICCRs, the Federal Police, Military Forces and even with foreign police services, e.g. Interpol. Among COI's activities, the following tasks play a crucial role in supporting CM in Bahia: (1) risk assessment that can support prevention and response actions; (2) the development, implementation and operation of monitoring systems for crisis (natural or man-made); (3) the development of crisis response plans; (4) simulations and trainings to evaluate the effectiveness of these plans; (5) crisis response actions; and (6) support in post-crisis reconstruction. All these six activities, and many others, produced a huge amount of information. Without tools and techniques, it is almost impossible to analyze this information to produce knowledge effectively.

Concerning the planning (Stage I), we decided to carry out a literature review and to run an *in-vivo* study involving a C2. We collected data over 30 months starting in the second semester of 2014 and finishing in the first semester of 2017 (Stage II). We will carry out a **deep** qualitative data analysis in the future (Stage III).

We collected data from several sources such as literature and direct from C2s, such as their environment, official documents, tools and practitioners' knowledge. We divide this stage in three substages: a) Formal Analysis of the Literature; b) Collect and Analyze General Data; and c) Collect and Analyze Target Data. In the following sections, we detail the data and how we collected it in each substage.

FORMAL ANALYSIS OF THE LITERATURE (Substage II.a)

The purpose of this collection was to provide research data to understand how the state-of-the-art on information visualization applied in EM is structured. We wanted to know common practices in existing studies, to identify research gaps and possible trends in the area. Thus, we performed literature reviews to understand the challenges and find out what researchers are publishing in the area. The focus was on diagnosing the problems and finding some academic solutions to them.

In this substage II.a, this data collection involved a systematic mapping study method, following the rules of Kitchenham et al. (2007) and Peterson et al. (2008).

Systematic Mapping Study in a Nutshell

The systematic mapping study is used to provide a structure for the research and its results (Petersen et al., 2008). The results may highlight gaps and trends in the research area.

First of all, we carried out a systematic mapping study to understand the use of visualization tools and their application in the CM area. We examined the most common visualization techniques applied to CM, as well as the environments and phases in which they were applied following a strict protocol to search and extract data. The papers were randomly divided among three researchers in such a way that two of them read each paper. If there was a disagreement in the paper data extraction, the third researcher gave his/her opinion to reach a consensus.

We designed our mapping defining the research questions, search string, inclusion and exclusion criteria, digital libraries and the classification scheme (categories and facets). We defined the period. We searched primary studies from Jan 01, 2001 to May 31, 2015. We decided to begin with the year of 2001 because Sept 11, 2001 is a milestone in Crisis Domain (Schmemann, 2001). We used the search string defined in Table 1. One relevant facet that we extracted was based on the Information Visualization Paradigm and Visual Attributes. For more details, see Dusse et al., (2016).

Table 1: Defined Search String.

(“Crisis Management” OR “Disaster Management” OR “Emergency Management”) **AND** (Visualization OR Visual OR Visualisation)

The first search found 5083 papers, from which 132 remained after passing through a set of filters. After the analysis of the first 132 primary studies, we used the snowballing technique to search in the references of each of them to find more studies. This led us to 49 more papers. We applied the same technique again to these 49 studies, and selected 15 more papers. We repeated the same process again and did not find any new primary studies, which finally gave us a total of **196 primary studies** to analyze. Figure 2 details the selection process.

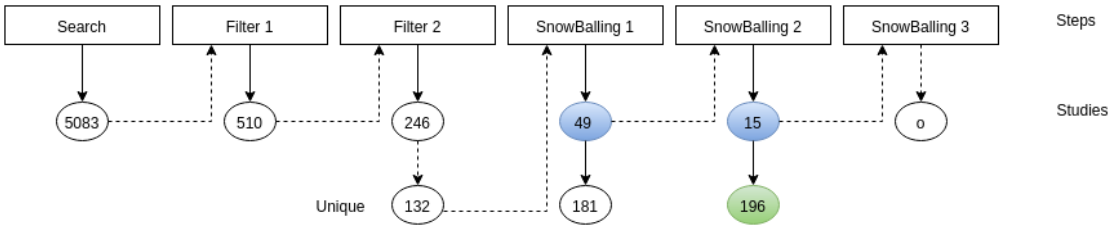

Figure 2: Primary Studies Selection Process (Adapted from Dusse et al., (2016)).

According to the results, the number of published studies that apply visualizations to CM is growing, demonstrating that the relevance and level of interest in the subject is progressing. Considering the distribution per year, we observed that the number of papers grew in 2007 and 2008. In 2014, it reached a peak (41 primary studies) with almost twice as many compared to 2013. When we did the search (May 31, 2015), we found 13 primary studies in 2015. We did not check the total number of studies in 2015. Our expectation is that it reached closer to 2014, as well as the number of works published in 2016 in this research area.

Figure 3 shows that most researchers use similar visual paradigms and attributes focusing on icons, colors, spatial position and shapes plotted on maps (*Geo-spatial 2D and 3D*) to visualize crisis information in a big picture, e.g. affected area and type of crisis. Crisis managers usually have to filter and search the available overview information to detail it on demand (Shneiderman, 1996) for the situation at hand.

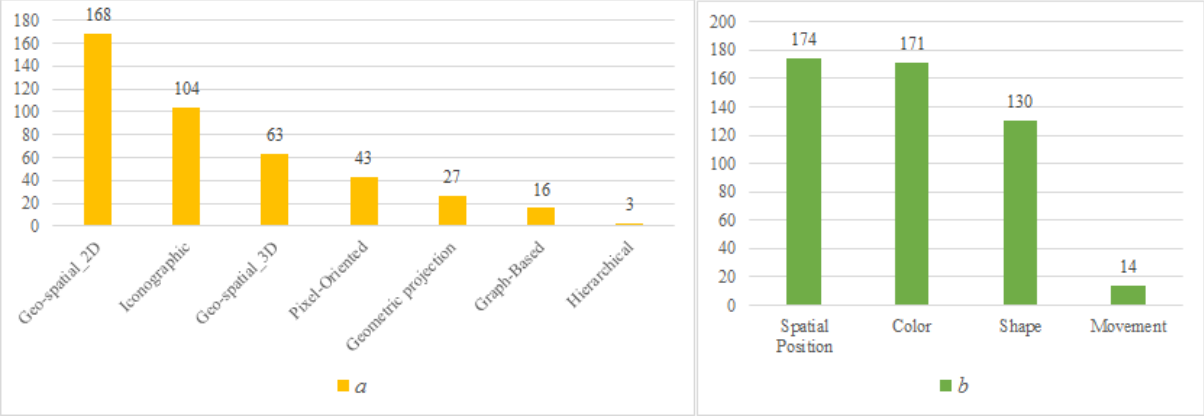

Figure 3: Publications per: a) Visualization Paradigm; b) Visual Attributes (Adapted from Dusse et al., (2016)).

The results from CM point of view show that researchers apply most tools in the response phase of a crisis. This demonstrates the need that crisis managers have for updated information about the situation in the location of the incident to support decision-making. Most works cover a specific type of crisis (e.g. earthquake, hurricane, flood, fire) but we also found some works that address crises in general. We classified 94% of the works as outdoor scenarios and only 11% as indoor. There are very few works in both scenarios (5%).

We also identified gaps and trends in the subject. One of these trends is the use of VA (Andrienko et al., 2007; Chae et al., 2014; Tomaszewski and MacEachren, 2012). We analyzed works that address VA in crises, which generated excellent results according to the authors. However, we consider these studies still incipient. They partially use the concepts of VA described in Keim et al. (2008) and the visualizations address a specific tasks and contexts (e.g. humanitarian aid and evacuation plan).

COLLECT AND ANALYZE GENERAL DATA (Substage II.b)

The purpose of this data collection was **broadly** to understand the overall dynamics of processes and activities, comprising the main aspects of how crisis managers analyze information for decision-making. Thus, we did a general data collection to know the key factors and to understand the challenges in the area. This substage focused on diagnosing the problems.

We had access to practitioners and to materials from Brazilian and French C2s. This data collection involved two methods: questionnaires and ethnographic studies following the rules of Crang and Cook (2007) and Robson (2011).

Questionnaires

During the Olympics and Paralympics, we ran an online questionnaire in which 49 officials from various agencies from different C2s participated (Table 2). The questionnaire is available online (in Portuguese)[2].

Table 2: Number of Respondents of the Questionnaire.

C2	COI	CICC-RJ	CICCN-DF	CEIC	TOTAL
Olympics	37	1	5	1	44
Paralympics	4	1	0	0	5

[2] https://drive.google.com/file/d/1Fr_5p7flrac2ksW-3-D8qLiWbd-duiwv/view?usp=sharing

We divided the questionnaire into 3 parts: (1) qualification of the practitioners, to know their competences and experience; (2) identification of the problems, to confirm if the problem that we are addressing is relevant; (3) suggestions for solutions, to listen to the insights from the practitioners pointing out solutions or workarounds to the problems. We had good feedback from the questionnaires. See Figure 4.

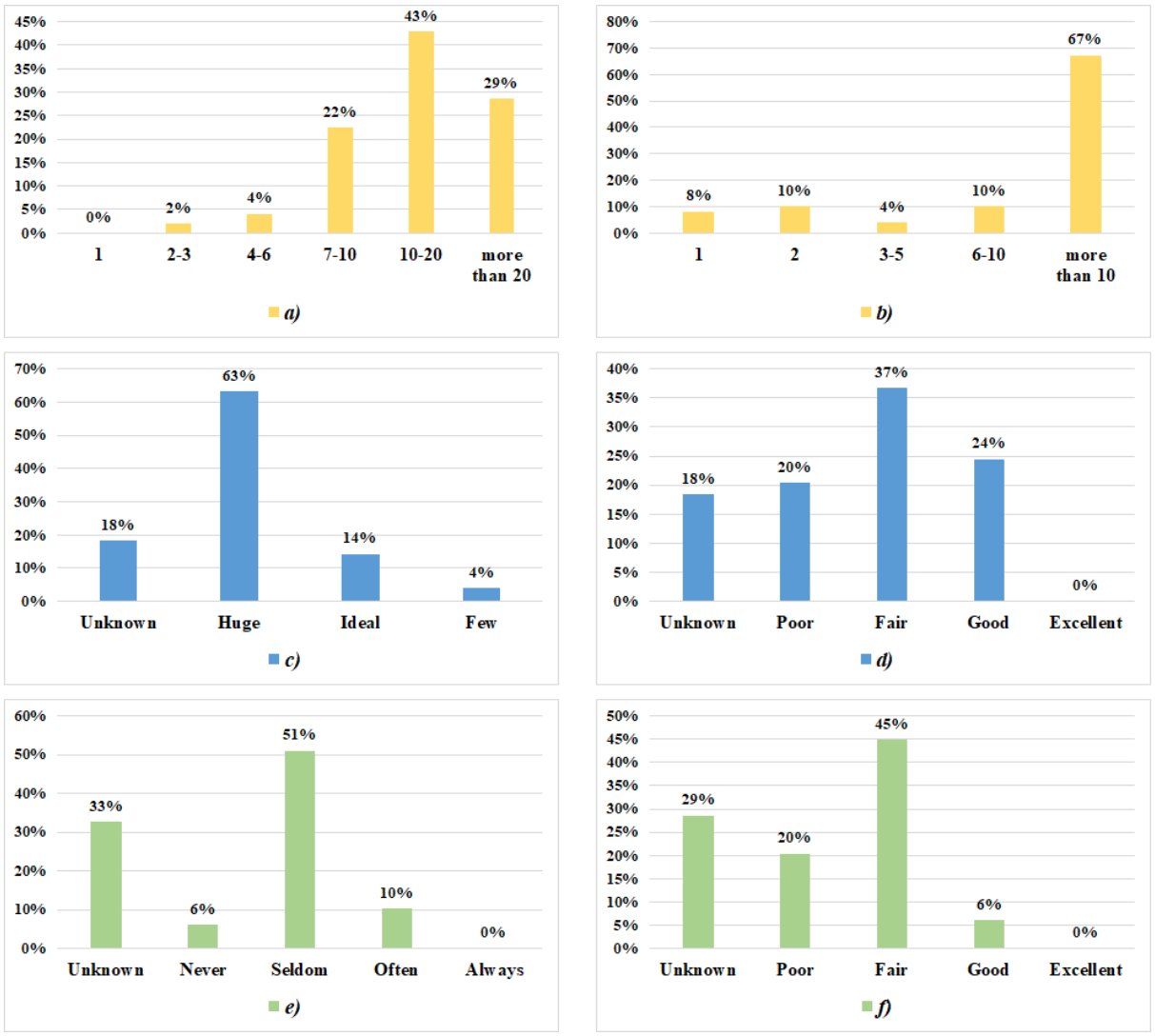

Figure 4: Summary of the questionnaires: *a*) work experience; *b*) work experience in C2; *c*) information quantity versus your analysis capacity; *d*) information quality; *e*) available tools to analyze information for decision-making; *f*) how visual tools represent the information.

First, we found that the majority of the participants are experienced, 72% had more than 10 years' work experience and 67% had more than 10 years of C2 experience (Figure 4*a* and 4*b*). Second, most agree that the quantity of information is huge (63%) and the quality is not good, 57% answered poor or fair (Figure 4*c* and 4*d*). Other relevant findings were: 57% ('*Never*' + '*Seldom*') said that there is lack of tools and 65% ('*Poor*' + '*Fair*') disagree that the existing tools provide effective information for decision-making (Figure 4*e* and 4*f*). None of the 49 practitioners answered '*Always*' for question of Figure 4*e* nor '*Excellent*' for the questions of 4*d* and 4*f*. The last item in the questionnaire was an open question for the practitioner to comment on anything about the survey. About 10 practitioners said that visualizations should improve their knowledge of the crisis operation supporting their activities. The compilation of the questionnaire data shows that there is much to contribute in the area.

Ethnographic Study

To complement our study, we carried out two ethnographic studies during the 2014 World Cup and 2016 Summer Olympics in Brazil. Ethnographic research methods have played a substantial role in sociological research during the last half-century and researchers are now using them in many disciplines, especially those that involve social and human factors (Crang and Cook, 2007). Ethnography is about immersing into the culture of a group for a period in order to participate in social relations, seeking to understand actions, how people act and make sense of their environment.

We adapted our ethnography with a limited degree of interaction. This was particularly helpful in enabling us to gather real, rich and detailed information about staff profiles, processes and technologies used for CM in COI.

We did our first ethnographic study in a partnership with the Brazilian Fraunhofer Project Center (FPC-UFBA) in the context of the Rescuer Project. The focus of this study was crowdsourcing, more specifically, we wanted to investigate C2 theory and practices to understand how crowdsourcing can improve CM decision-making.

The COI prepared itself for possible crises that might happen during the 2014 Brazil FIFA World Cup. The managers called this preparedness '*World Cup Operation'*. We identified some general requirements, such as the main agencies working in this operation, their main activities and the main resources that they used for analyzing information and communicating with each other. We did not witness any impactful crisis, so we did not learn much about crisis responses. However, we could observe that despite having tools with some kind of visualization, they were not exploited much for information analysis for decision-making.

The authors did a second ethnographic study. Unlike the first one, the focus was C2 visualization, more linked to the objectives of this paper. We wanted to understand how visualization could support decision-making. We studied from the collection of crisis raw data to the decisions themselves, going through all the steps of the transformation of the raw data into information including how to visualize the information produced.

The COI prepared itself for possible crises that might happen during the 2016 Rio de Janeiro Olympic Games. The managers called this preparedness '*Olympics Operation'*. We found and confirmed the same requirements as the previous ethnographic study, however, this time, we focused on how the practitioners visualize the information. Again, we did not witness any impactful crises, so we could not observe effective crisis responses. We confirmed what we observed two years before in the '*World Cup Operation*'. The crisis managers have visual tools but they are underused in the information analysis for decision-making.

Besides these two stricter studies, we also observed the day-to-day activities, not necessarily large operations, for example simulated exercises. On two opportunities, the crisis managers of the state of Bahia simulated terrorist attacks during a football match in the Fonte Nova Arena[3], the football stadium where the World Cup and Olympics football matches took place in state of Bahia. The Bahia managers carried out another exercise on the Subway system simulating bombs, kidnappings and shootings in an area of mass transport. Many agencies participated in these exercises, training their operational forces for possible crises.

We found that the agencies in COI uses a common tool in real operations and in the simulated ones too. This tool is *Risk Manager* and it was developed by SESGE and provided for Brazilian C2s. In our observations, we noted that *Risk Manager* is underused and almost all agencies use their own tools to collect and analyze only relevant information for their agency and their attributions. This impacts data integration. We found that decision makers hardly ever used the information visualized by these tools to make decision. We also found that the information analyzed in these tools is compiled with other isolated information[4] in a printed report. If there is a need, the political authorities make strategic decisions based on these reports.

In all of these observed scenarios, we consider it is possible to go further in the use of visual tools and VA has potential to help in this area.

COLLECT AND ANALYZE TARGET DATA (Substage II.c)

[3] http://www.itaipavaarenafontenova.com.br/

[4] Isolated information is the type of information that is added to a report that was not collected using a rigorous process, e.g. information from informal communications or tacit knowledge from the crisis manager.

The purpose of this data collection was to understand **deeply** the overall dynamics of processes and activities, comprising the main aspects of how managers analyzes crisis information for decision-making and **primarily** if we can improve it by using **visualization techniques**.

Two methods were used. The first, we carried out a comparison of visualization tools available in the C2s that we accessed. The second, we conducted an empirical survey (Wohlin et al., 2000) based on semi-structured interviews (Seaman, 1999), following a strict protocol to collect more target data. In this substage, we focused on possible solutions.

Comparison of Visualization Tools

We planned to compare visualization tools developed for CM to which we had access. We aimed to know and understand if the tools implement VA. Our aim was not the tool itself, but the visualizations that the tools provided.

We analyzed seven visualization tools in total from four C2s (COI, CICC-RJ, CEIC and DZPPP), the Ushahidi tool[5] and two versions of the research project Rescuer[6] tool. In general, C2s use proprietary tools purchased from suppliers or developed internally. Ushahidi is an open source platform that has been used in several crises such as the Haiti earthquake. Rescuer tools are deliverables from an international research project with European-Brazilian partnership. The choice of these tools proved very useful. We could compare C2 tools in production against open source tools and against research project tools.

To compare the tools, we used the same facets as Dusse et al., (2016). We divided the facets in two classes: VA facets and CM facets. In the former, we extracted the visual paradigm, visual attributes, interaction mechanisms, context-sensitive and user-centered. In the latter, we extracted phases, types, environments, platforms and data sources. The complete extraction is available online[7].

All the tools provide a combination of icons and shapes plotted on maps. This visual paradigm presents an overview of the crisis field. The details of what is happening there are not present in the views. Crisis managers need interactions mechanisms (e.g. zoom, filter, sort, aggregate, among others) to see the details. All the tools make use of the same paradigm, maps, icons, shapes, colors and so on to all respective users. In general, the visualizations of each tool are the same for all types of crises. Figures 5 to 12 show print screens, or pictures taken, of visual examples of the tools analyzed.

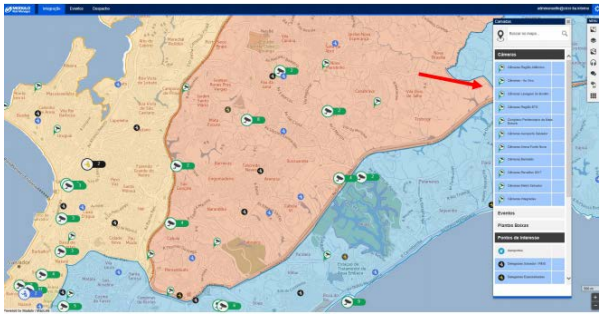

Figure 5: COI (*Risk Manager* 1)

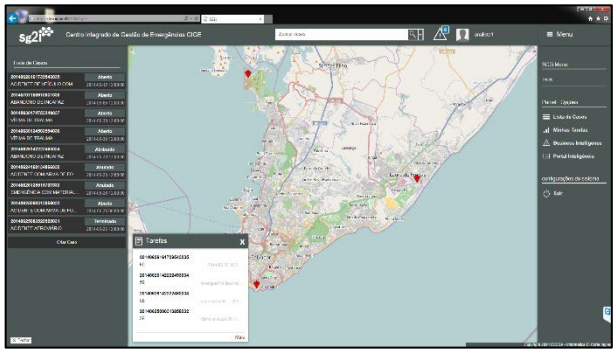

Figure 6: COI (*Risk Manager* 2)

[5] https://www.ushahidi.com

[6] http://www.rescuer-project.org/?lang=en

[7] https://drive.google.com/file/d/1_SNgU0TqgGF7VwSKd8_Z3y70LhvgEU6o/view?usp=sharing

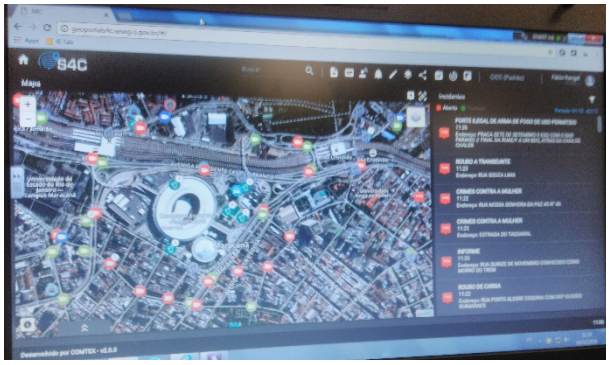

Figure 7: CICCRJ

Figure 8: CEIC

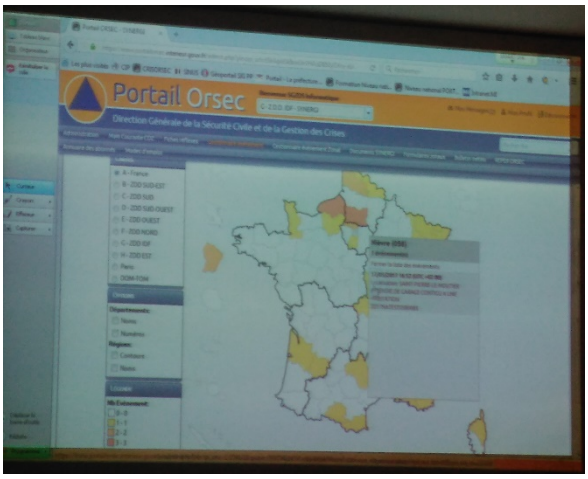

Figure 9: DZPPP

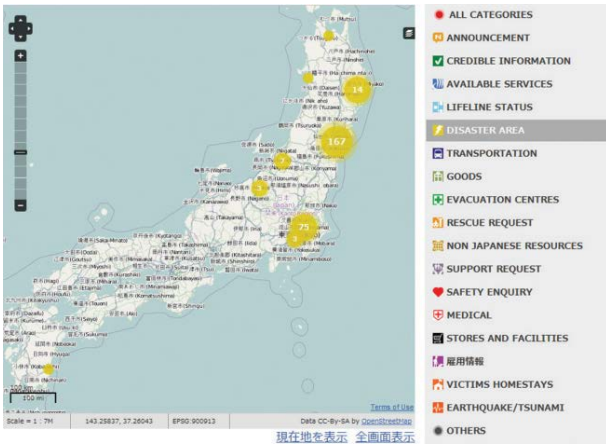

Figure 10: Ushahidi

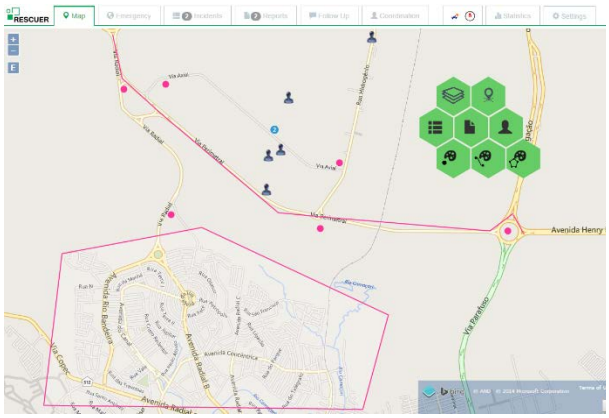

Figure 11: Rescuer v1

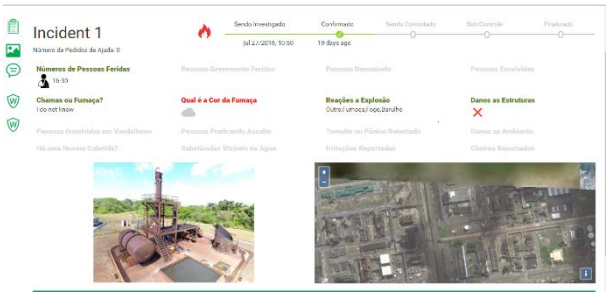

Figure 12: Rescuer v2

They do not take into account the particularities of the agencies. For example, one icon plotted the letter ‘H’ on crisis map which could represent a Hospital for one agency, while it could represent a Hydrant for another. Other examples are temperature and time zone. An agency could use degrees Celsius to measure temperature while another agency could use Fahrenheit, similarly one could use the local time zone while another GMT.

In addition, we found that all the tools are used in response phase, outdoor environments and they use web platforms; except for Ushahidi, which has a mobile version.

In all of these analyzed tools, we think that it is possible to go further in the use of VA in visual tools. As the state-of-the-art, we identified that the state-of-the-practice is neglecting some relevant dimensions, e.g. being

context-sensitive and user-centered. We expect that research and development in VA in the crisis context can improve current tools and, consequently, improve decision-making in CM.

Survey Protocol (Interviews)

During the substage II.c, we used a second method to collect target data. We conducted semi-structured interviews with six crisis managers (domain specialists) from different places and even countries: five Brazilians and one French, from four different C2s, three specialists from COI, one specialist from CICC-RJ, one specialist from CEIC and the last one from DZPPP. Since the interviewees had strict time constraints, the interviews took no more than 30 minutes on average.

We formalized the interviews in a Survey Protocol which defines the method for data collection based on the rules in Ciolkowski et al., (2003). The survey process consisted of six steps:

Step 1. **Survey Definition:**

We determined the goal of the survey to investigate what the factors are and how they influence CM decision-making and how we can treat these factors using VA.

Step 2. **Survey Design:**

We designed the survey (next steps 3 to 6) defining subjects, materials, tasks, criteria, attributes, among others. We chose the methods to collect and analyze the data.

As regards collecting, we decided to conduct semi-structured interviews, with at least three subjects (domain specialists). We chose a semi-structured interview because it is open-ended, more dynamic, and allows improvisation on the part of the interviewer and scope for a fuller exploration of the studied objects (Runeson and Host, 2008).

Based on the data already collected, we defined **three preliminary key factors** to guide the data collection and analysis. Table 3 describes these factors.

We formulated the questions and decided to do a pilot interview (Ciolkowski et al., 2003). The pilot was important to make sure that the protocol was reliable and robust. Then we chose the three first subjects and asked them to recommend other potential subjects. The design or protocol of the survey is available online (in Portuguese)[8].

Table 3: Preliminary Key Factors.

Id	Key factors	Description
1	Raw Data	This key factor refers to a set of values of variables collected from a source, with no handling, with which one can obtain information to support key factor 2.
2	Information Visualization	This key factor defines the area that we are investigating to support key factor 3.
3	Decision-making	This key factor defines the main process that our study aims to support in the CM area.

Step 3. **Survey Implementation:**

We prepared the material necessary for the interview (subject invitation, room, audio recorder, paper, pen, etc.). In this step, we also did a pilot study to refine the Survey Protocol, however, we

[8] https://drive.google.com/file/d/1XXU6IbMwtFV59hhJuQsPESmq4hslNfVi/view?usp=sharing

did not use the pilot data in our analysis. We used it for the sole purpose of evaluating the effectiveness of the Protocol.

Step 4. **Survey Execution:**

We carried out the interviews themselves. As mentioned, we carried ou six interviews with practitioners, from four different C2s and two different countries. We recorded all the interviews.

Step 5. **Survey Analysis:**

Between the interviews and the analysis, we transcribed the interviews verbatim by listening and re-listening to the recording and transcribing them. We carried out all the interviews in Portuguese, apart from one in English. Concerning this specific interview, after the transcription, we translated it to Portuguese. The transcripts of the six interviews produced 116 pages of text.

We discarded one interview, the one with the specialist from CEIC, because the subject's answers were too superficial and, despite our attempts, he was not able to make the link between the preliminary key factors. We concluded that this subject did not have adequate knowledge to meet our goals defined in Step 1.

After the transcription of all the interviews, we sent emails to the subjects, attaching the transcribed text and the audio of their interview. In general, in an interview, people do not have much time to think about their answer. The purpose of the emails was to give them the opportunity to review their answers in their own time. As the interviewees work with strict time constraints, few returned our emails. Those who replied to our emails did not make relevant comments.

We also interacted with the subjects, days after the interviews, mainly with the ones that worked in COI. Whenever doubts arose regarding what some subject meant at some point in the interview, we looked for them and tried to clarify the doubts. These informal conversations with the specialists took no more than 2 minutes on average and they were repeated countless times. Even though these informal conversations do not constitute the same scientific evidence as the Survey Protocol, for example, we did not plan nor record them, the data collected in these conversations were important for our study, mainly to mitigate some threats of validity.

In our preliminary analysis, we found that according to the subject's answers managing a crisis is very hard and complex. Many factors can influence the whole process, from the planning and data collection to the decision-making and the action execution. In general, we found that the subjects cited some factors frequently: C2 doctrine, lack of resources, the type of the crisis, political issues, vanity between agencies, staff motivation and the profile of the information analyst. About the visual tools themselves, they outlined that tools are not valued as they should be. They added that they need investment and research in this area. We conclude that in a multidisciplinary domain, such as CM, it is very hard to prioritize the factors that influence decision-making and it largely depends on the context. You cannot neglect any factor, otherwise the response can be disastrous.

Step 6. **Survey Packaging:**

The objective of the packaging step is to report the survey and results so that external parties can understand the results and their contexts. We considered this text part of the packaging.

The interviews and the other collection methods were complementary. In some situations, we identified an issue in the interview and were able to focus on this issue using other methods and, at another time, we obtained data through literature, observations or questionnaires and had the opportunity to go deeper while interviewing. We compared, crosschecked and triangulated the gathered data.

Among all methods used here to collect data, listening to the domain specialists was the most relevant and scientific-based data collection in our study. The strict protocol used in the collection and the relevance of the data collected demonstrate this. It is important to cast light on the respondents' experiences. Their narrated experiences are very hard to gather from documents or ethnographic studies. The data collected in the interviews was huge and requires **further** analysis. We plan to do this.

RESEARCH FINDINGS

We summarized the main research findings in Table 5.

Table 5: Main Research Findings of Data Collection.

SUBSTAGE	METHOD	MAIN RESEARCH FINDINGS
II.a) LITERATURE REVIEW	**Systematic Mapping Study**	A1. Number of published studies that apply visualizations to CM is growing; A2. Most of the research uses similar techniques such as icons and shapes plotted on maps; A3. The studies in *Response* phase prevail; A4. The studies in *Outdoor* scenarios prevail, A5. The studies of a specific crisis type prevail; A6. VA is a trend in the area but its full potential is not being applied in the state-of-the-art
II.b) COLLECT AND ANALYZE GENERAL DATA	**Questionnaires**	B7. The quantity of information to analyze is huge; B8. The quality of information to analyze is not so good; B9. There is a lack of tools; B10. The practitioners disagree that existing tools provide effective information;
	Ethnographic Studies	B11. Understand the operation coordination of a C2, focusing on the use of visual tools in the decision-making process; B12. Lack of integrated visualization tools; B13. The agencies use their own visualization tools for their specific activities; B14. The common tool is underused; B15. The tools are used mainly in the *Response* phase; B16. The tools are not effective for *Indoor* scenarios; B17. The common tool is not context-sensitive nor user-centered; B18. Lack of use of visualizations in decision-making;
II.c) COLLECT AND ANALYZE TARGET DATA	**Comparison of Visualization Tools**	C19. All tools use similar techniques such as icons and shapes plotted on maps; C20. The paradigms of visualization of each tool are the same for all types of crises; C21. They do not take into account the particularities of the agencies; C22. The tools are used in *Response* phase; C23. The tools are used in *Outdoor* scenarios; C24. The platforms of the tools is practically 100% web;
	Survey Protocol (Interviews)	C25. Understand the use of visualization tools in the decision-making process, what factors can impact it; C26. They do not take into account the particularities of the agencies; C27. They do not take into account the profile of the analysts; C28. The tools are used in *Response* phase; C29. The tools are used in *Outdoor* scenarios; C30. It is hard to prioritize the factors that influence decision-making and it largely depends on the context C31. Lack of use of visualizations in decision-making;

By crosschecking the findings presented in Table 5, it is clear that some methods come to the same results. For example: *i*) A2 and C19; *ii*) A3, B15, C22 and C28; *iii*) A4, B16, C23 and C29; *iv*) A5 and B13; *v*) A6 and C31; *vi*) B17 and C30; *vii*) C21, C26 and C27.

Our investigation presented findings from a multi-method approach that demonstrate that further researches in the application of VA can tackle the challenges of information visualization to support decision-making in CM.

TREATS TO THE VALIDITY

There are some threats to the validity of this study (Wohlin et al., 2000). We present them below with the strategies for their mitigation.

Concerning the Systematic Mapping Study, the threats to the validity can be found in Dusse et al., (2016).

Concerning the interviews that we carried out, as threats to the construct validity, poor survey design based on a poor theoretical basis could figure. To mitigate this, we did a pilot interview to evaluate our survey protocol.

Regarding conclusion validity, CM is complex and dynamic therefore; data collection for scientific research in this area is also complex. The dataset collected could be incomplete or inconsistent. We mitigated this threat by collecting data from different sources and using different approaches; i.e. literature, documents, software tools, observations, questionnaires, interviews. In addition, we compared, crosschecked and triangulated all the collected data. In order to mitigate this threat, we interacted repeatedly with the subjects by email or informal conversations to validate our work.

As threats to internal validity, the researchers responsible for data collection and classification came from the same organization. This may have led to bias in the interpretation of the concepts analyzed. We could not mitigate this threat.

As threats to external validity, we believe that the data collected is representative of CM worldwide. We attempted to mitigate this threat because we collected data from more than one C2. In fact, we are conducting an exploratory study in COI but we studied three other mature C2s too. In addition, the qualifications and work experience of the specialists minimized the impact of this threat.

Moreover, a final threat is that all the subjects are domain specialists and not VA specialists. While they use visual tools in their work routine, they do not have deep knowledge in the area of visualization. We did not mitigate this threat, but we intend to assess it in our future work with visualization specialists.

CONCLUSION

This paper presents an investigation of the use of VA in the CM context by a multi-method approach. We did a formal literature review through a systematic mapping study and collecting local knowledge and data from C2s in Brazil and France through *in-vivo* studies such as questionnaires, ethnographic studies and a survey (interview) protocol. Researchers and practitioners can use the data collected in this work to identify research directions or to evaluate new visualization tools.

Although the use of massive visualizations for sense and decision-making is a reality found in literature and among practitioners, our findings revealed that it is still not clear what information is required in decision-making in a given crisis context. Moreover, the amount and the heterogeneity of crisis information are real-world problems that need investigation to identify gaps.

We conclude that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice. We identified a lack of suitable visualizations and a research gap in this area. We expect that by extending the research and applying VA techniques and tools, using effective and flexible visualizations will contribute to the crisis domain.

As said before, this paper reports the preliminary work of a broader study that we are carrying out. Our final objective is to support CM decision-making with a computational reference model based on VA. To finish this model, we will carry out a deep qualitative data analysis (Stage III of Figure 1). We assume that to produce scientifically acceptable findings to answer the research question, a high level of rigor in the analysis of the data collected **is required**.

Finally, we plan to carry out further interviews to assess the data collected and to refine it. We also need to assess the data with visualization specialists.

ACKNOWLEDGMENTS

The authors would like to express sincere thanks to COI, CICCR-RJ, CICCN-DF, CEIC and DZPPP for their collaborations and for providing a portion of the data used in this paper. This project is partially supported by RESCUER project - CNPq Grant 490084/2013-3.

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