A Decision Support System for Medium-Sized Emergencies

Andre Engelbrecht, Adriana S. Vivacqua, Marcos R. S. Borges
Post-graduate Program on Informatics (PPGI)
Federal University of Rio de Janeiro (UFRJ)
Rio de Janeiro – RJ – Brazil
andrefelipe@ufrj.br, avivacqua@dcc.ufrj.br, mborges@nce.ufrj.br

Álvaro Monares, Sergio F. Ochoa, José A. Pino
Deparment of Computer Science
Universidad de Chile
Santiago - Chile
{amonares, sochoa, jpino}@dcc.uchile.cl

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***Abstract*. The decisions made by the operation commander in emergency situations should be made quickly to save lives. To avoid late or bad decisions, the commander must construct a situational awareness. The irregular arrival flow of information, uncertainty, information overload and lack of persistence are the main factors that hinder this task. To minimize these effects we propose an architecture composed of mobile devices and a decision support system to be used in the command post. The main point in the system design is the cognitive overload. Therefore, heuristics about the usage of the information by experienced commanders were elicited and implemented.**

I. INTRODUCTION

The emergency situations affect the life of several people around the world, either economically or with human losses. When dealing with urban emergencies, due to the demographic concentration, a fast and effective response is fundamental to reduce its impact on persons and civil infrastructure.

Typically, emergency management models are based upon a Command and Control structure [1], divided in two groups:

(a) The first group, known as *First Responders*, works in the front line of the emergency, rescuing victims, providing medical care, and guiding people, among other activities;

(b) The second group is named *Command* and it is usually located in a room or a control centre. The aim of the command is to evaluate risks and make decisions, as well as follow up the progress of activities. This group may be also located in mobile units, called “command post”, in which there is one individual in the position of operation chief or operation commander.

The decisions made by an operation commander in a command post are related to the evolution of the work and they should be made quickly to save lives or avoid the aggravation of the problems. These decisions are based in little information that arrive unordered, often by radio, and cannot be persisted.

Either delayed or inaccurate decisions can entail more damage to the victims and to the economics or even jeopardize the response team. In these cases, it is vital that these individuals have both updated and accurate information, so that they can understand the situation, in order to make their assessments and decisions as safe and correct as possible.

In the literature, there are many works that prioritize the management of emergencies in disasters of great magnitude, as MIKoBOS [2], OASIS [3] and SHARE [4]. In such cases, it is plausible to think that communication infrastructure will not be available and, therefore, the typical solution is to make available several redundant digital communication methods. Moreover, these solutions prioritize the provision of current information to the Command Center for the decision-making at highest level, because they were thought to support major disasters. However, for small and medium-sized events, the deployment of this kind of complex infrastructure in the incident location can be time consuming for response teams. Likewise, the decisions do not need to be made at higher levels of the hierarchy, being possible, and even desired, the shortening of the information flow only up to the command post.

This work aims to support operation commanders, located in command posts, managing search and rescue teams in urban emergency situations combining more than two companies of the same agency, at least two agencies or any amount of resources working in turns, situations in which it is important the information sharing. These values were obtained by interviewing operation commanders and we believe, initially, that for events with lesser values the systems can turn the action of involved responders more laborious and, thus, it can harm their performance.

Situational awareness (SA) plays an important role in decision-making of commanders in emergency response operations. According to Mica Endsley [5] the construction of this perception, individually, occurs in three levels: (1) Perception of the elements of the situation, (2) Comprehension of the situation and (3) Projection of the future state.

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The concepts and models proposed by the author about the perception and its related factors, which influence the process of decision-making, remain widely accepted in many areas. Regarding to the SA in working teams, Stanton [6] suggests that it is distributed between human and non-human agents who compose the system, proposing an overview applied to system level of Endsley's theory.

Both human and system factors play an important role in the development of a technological solution that supports commanders' decision during emergencies. The decision-making in this type of event does not involve only aspects typically found in business environments, but also anxiety, attention, cognitive overload, improvisation, uncertainty, pressure and stress.

To the command it is necessary to have the feeling of possessing the relevant information and observations for the correct interpretation of the situation to overcome these issues, thus preventing making bad decisions. Therefore, it is possible to design a plan of action to resolve existing problems [7].

According to Sapateiro and Antunes [8], the construction of the situational awareness is one of the biggest problems to be considered in emergencies. The great volatility of this information, its irregular arrival flow, or its lack/overload are factors that hinder its construction and maintenance.

II. Related Work

Proposals for decision support in emergency situations typically aid the strategic command. This is located in the Command Centers and evaluates measures to control the whole situation, supervising several operation commanders. In this group, there is still a division of proposals into two types: those that aim to increase situational awareness and those that pretend to simulate future projections.

Ernst and Ostrovskii [9] and Andrienko and Andrienko [10] propose intelligent visualization of situational information in Geographic Information Systems (GIS). Therefore, both use thematic visualization, interpretation of the user's necessity and intention and domain specific knowledge, documented in ontologies. Ernst and Ostrovskii also advocate the use of 3D images to improve orientation and to provide more details about the area, beyond considering the temporal dimension of events on objects' representation.

Monares *et al*. [11] propose the use of mobile devices by responders for providing information regarding to location, status and assigned tasks of teams to the Command Center. It's also possible to send photos taken by these devices to the server in the centre.

In the second type, which intends to recommend alternative approaches, it is common to incorporate expert knowledge and to develop models that simulate and prescribe assessments used in planning future actions [12, 13, 14]. Figure 1 illustrates a decision support system used in Louisiana (USA) to predict the evolution of flooding.

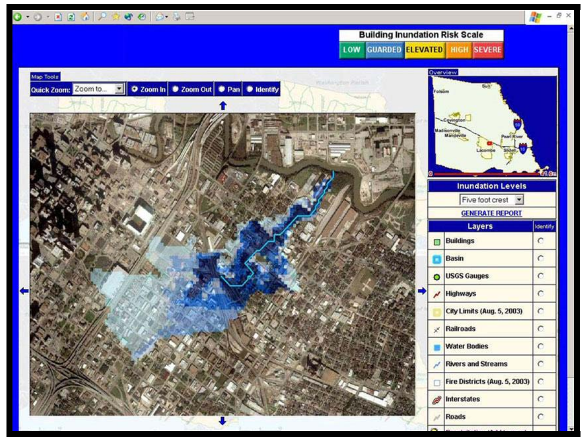

Figure 1. Flooding prediction model used in Louisiana, USA. Source: NVision, 2010

There are few approaches that prioritize support for situational awareness and decision-making in the Command Post. It is a complex task to propose technology for it because the necessity for information in local command is much diversified. Ancient procedures cannot be modified in a manner that takes an individual from the front line to deal with technology or that hinder your mobility to perform his activities.

Jiang *et al*. [15] propose sharing the current contextual information between the operation teams and the command post implicitly by using sensors. It is thus possible, for example, to the operation commander to take notice of a danger that a team is exposed to and decide for their withdrawal. Bergstrand and Landgren [16] use live video to increase situational awareness of command. The authors found that the solution also helps the communication between the Command Post and the Command Center. Figure 2 shows that the video can contribute to the notion of how is the location of the incident, what challenges are facing the teams and what are their needs, as a complement to verbal reports.

Figure 2. Vídeo showing the teams trying to rescue a victim trapped in an overturned car

The representation and visualization of such contextual information is also subject of current study. In this case, one of the most common solutions has been the use of ontologies [17, 18]. This kind of representation does not require the prediction of all type of relationships in advance. Kokar, Matheus and Baclawski [19] formalized the key terms in this field using the Web Ontology Language (OWL), a language that allows machine usage. The authors defined types, classes and relationships that allow instantiating facts about the world and, from these, infer other new.

Fitriane and Rothkrantz [20] extended this approach by adding the **overlay** operation to create a unified vision of the world based on multiple views of the users in field. Once information is received, these may be added to the previous ones or delayed, if it conflicts with knowledge already stored, until they are strengthened by new evidences. Although aggregating this decision mechanism on the conflicting information, different ways of providing it are not studied. The information is only checked with others related to the world described by the ontology to decide if it is going to be displayed or not. Moreover, in this type of approach, the concepts are defined according to the real world and do not contain metadata that may help provide better information.

Sapateiro and Antunes [8] propose another emergency response model based on collective construction of situation awareness. The authors utilize Situation Matrixes to relate two different dimensions of relevant factors, such as, for example, actors and actions or actors and resources. These relationships have their meaning expressed by a semantic vector (e.g., actors who are impacted by certain actions).

III. Our Proposal

The purpose of this work is to support the operation commanders' construction of the situational awareness and, therefore, their decision-making in medium urban emergency situations. Typically, the construction of the context perception occurs through the sharing of information among the teams involved and it is realized via radio. The teams, even working in different sectors, use the same frequency so that everyone might have access to information and build a similar picture about what is happening. This solution has been used for a long time and can be considered reliable for extreme situations, since it does not depend on fixed networks and electricity. However, its problems are also well known. The most relevant problems from the command viewpoint concern the occupation of the channel, which prevents the simultaneous transmission, message's truncation and lack of information persistence. To decrease the volume of traffic, some conventions have been adopted, for example, the definition of a common vocabulary among the involved organizations and standards for usage of the channel. However, these measures are not sufficient to prevent the arrival at the command of information from different sectors or work teams in a fast sequence, increasing the complexity of the cognitive work or even loss of data.

The task of proposing technology solutions to support work in an emergency situation becomes more complicated as more is known about how it is actually performed by rescuers. Despite the benefits they can bring, it is always necessary to consider aspects such as mobility of the individual, weights to be carried and occupation of the hands. Therefore, mobile technologies are more suitable for these cases.

Nevertheless, one must try to make the use of technology as easy as possible and in order to cause the least impact on the tasks. Therefore, the transmission of information should not demand more than a few taps on the device, being preferred to send them implicitly (e.g. location of the team by GPS).

Considering these aspects, the proposed architecture was designed to support the teams to share information among them and with the command post regarding its observations about the evolution of the situation (see Figure 3).

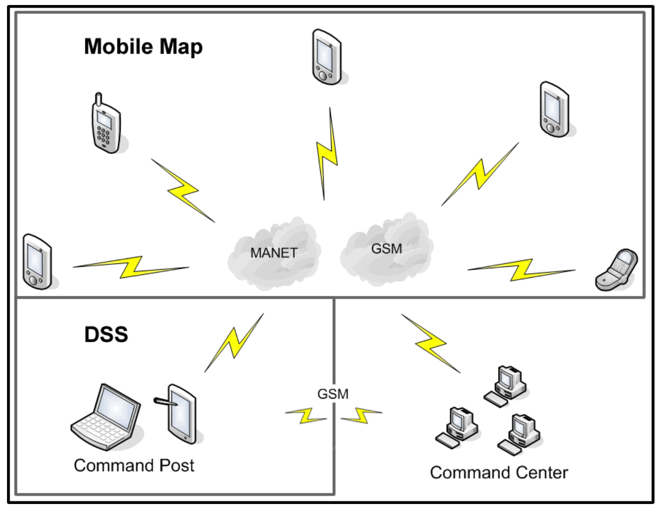

Figure 3. General Architecture

The choice for mobile ad hoc network (MANET) is justified by the possibility of working inside large structures or on areas with no coverage of other types of networks. The operation of this type chosen is independent of connection to the Internet or telephone service. This makes it possible for local teams and the command post to exchange information without worrying about coverage and shadow areas of mobile technology signals.

To the long distance contact, such as, for example, with teams outside the place of the incident or the central command, the standard Global System for Mobile Communications (GSM) was adopted. With it, one can get, for example, information about units of other companies that are available to act as reinforcement in the situation or transfer photos to the control unit.

The same care taken to introduce new technologies in operation teams' work should be taken with the command. A key issue to be considered is the volume of information available. This amount should stay in a narrow strip between the lack of crucial data for the decision and its overload. In both cases, the cognitive work of individuals is pressed against the limits of error, which can result in more damage and loss.

A decision support system in the command post may further contribute to the risk assessments and selections of choices by the operation commander, beyond reducing the communication volume in radios through the exchange and persistence of digital information.

The availability of this information must be made to prevent the decision-making problems previously mentioned and with as little interference as possible in the current manner of work of these commanders.

For this purpose, the system was designed to run on a light and easy to use device, for instance, a tablet PC or notebook, and to display the most important data considered in each moment of the user interaction, however allowing access to detailed data when desired.

In order to determine the information needs of the command one must first understand how their work is done and what types of information is exchanged between team members and command. Diniz *et al*. [21] define, in a simplified manner, this process as a cycle composed of three steps. First, the situation is understood and decisions thereon are made. Then, the chosen actions are implemented, what impact, along with other external events, the situational context. This generates the need for updating the information about the emergency so that new decisions can be taken. Diniz and his colleagues refer to this kind of knowledge as current contextual, distinguishing it from the previous formal knowledge, which is present in textbooks, maps, plans of buildings etc., and from previous personal, which is tacit and was incorporated during experiences, trainings conducted or other forms of personal learning.

The combination of these three types of knowledge constitutes the basis for the decision-making of the operation commander. Thus, for this purpose the system should consider the role of each type in individual's cognition.

Thereafter, the availability of information was arranged to operate on demand as shown in the diagram in Figure 4. This means that when the commander demands knowledge about a particular object of the situation, he gets a set of associated data from other objects to satisfy the main decision-making. If he needs further information he can go deeper into an object. Tacit knowledge of commanders with large experience in emergencies was collected aiming to obtain these data combination rules. This representation aims to reduce cognitive overload, considering the major decisions that are taken and the information upon which it is based. Figure 5 shows an example of the information combination for a structure belonging to the incident area.

The previous formal information is, normally, consulted on demand. Thus, it was depicted in the form of points of interest displayed in the incident area map. Its visualization can be activated or deactivated according to the need of the command to combine current contextual knowledge with previous formal knowledge.

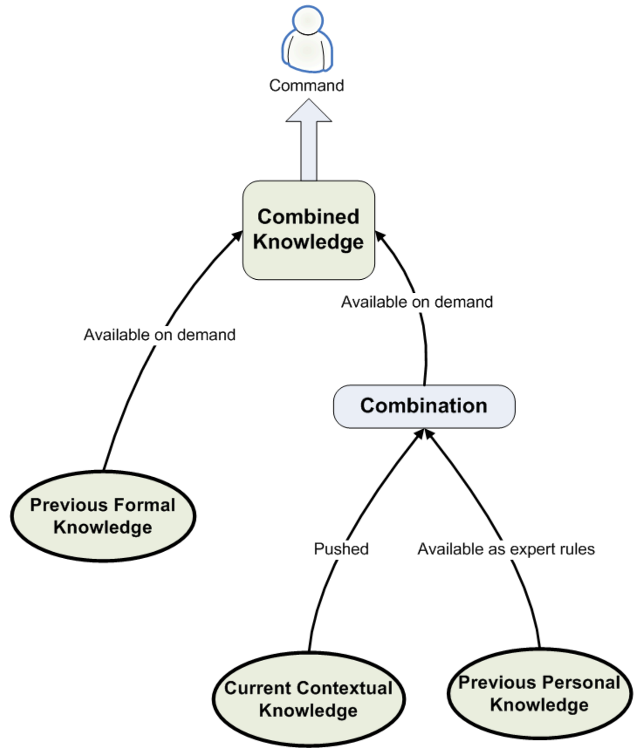

Figure 4. Knowledge Combination Scheme

IV. DECISION SUPPORT SYSTEM

The proposed architecture takes advantage of the existence of an application, called MobileMap [11], which runs on mobile devices and connects to a server running in the command center via GSM. The server gathers information about the dispatched vehicles and its current state. On the other side, mobile devices are able to send, beyond this information, photos taken at the incident area. However, its key features include receipt and storage of points of interest.

This tool also allows responders to consult incident area maps and points of interest, locate a destination and know your own travel direction and status of other vehicles.

While MobileMap serves the people that act as sensor in the field, providing information and communication, the decision support system (DSS) is responsible to give the situation awareness to the commander.

The DSS transforms the data obtained by the first responder in the field and makes the correspondence with the ontology. Finally the data could trigger some alarms that require the immediate attention of the commander.

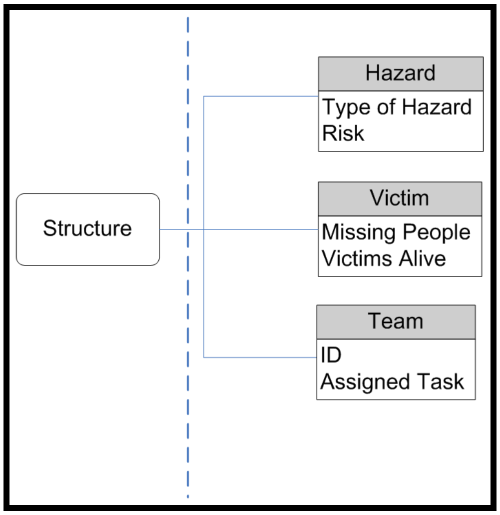

Figure 5. Information from other objects related to a Structure

In our case we have indentified 7 conceptual entities, which are fundamental to the analysis of the commander in a medium-sized emergency. These entities are: risks, structures, victims, teams, facilities, vehicles and equipments.

Risks – risks are important for the decisions about security and withdrawal of teams. Large exposures may determine whether or not they will work in a particular location. It is very important to know the type and severity of the hazards that can impact the teams' work.

Structures – the kind of structure, number of floors, estimated number of people living or working at a structure at the disaster moment, among other information, contribute for allocation of staff and equipment in the search stage.

Victims – after searching potential victims starts the rescue stage. The numbers of missing people and, mainly, of victims alive drive the decisions about allocation of human and material resources in this phase.

Teams – teams are the people working in the emergency field. They work for various heterogeneous agencies and must act in a coordinated form to achieve the emergency response goals. It is very important to the commander identifying each team, its agency, assigned task and quantity of members.

Facilities – facilities are places that can be required during the work. It can serves for team's resting, victims transportation, amongst others. Its location and availability are the data most often inquired by the command.

Vehicles and Equipments – like teams, these are the resources available to face the emergency.

Risks, structures, facilities, vehicles and equipments combine previous formal knowledge and also current contextual knowledge. On the other side, the information about victims and teams are always situational dependent.

These entities are represented by icons on the interface and the relevance of the object defines its size. This strategy aims to decrease the cognitive load of the commander. For instance, a mall in the middle of the night has less relevance than in the day.

The relationships between these entities were defined in order to answer the main questions of the command. For instance, when one commander wants to get information about a Team, he is usually interested also in Equipments in use or not by this team, Risks that can impact the responders or data about Structures where they are working. When asking about a Structure, the command usually wants to get information about Teams working there, victims in the place or the kind of hazards that threaten the teams and/or victims. So for each kind of entity being visualized there is a group of questions that can be answered with the data available from these relationships. To enhance the access speed to information and, at the same time, avoid the cognitive overload, the data from other entities related to the one being visualized were prioritized and only the most important are shown.

The entire set of relationships elicited is showed in Table 1.

TABLE I. ENTITIES RELATIONSHIPS

Entity	Related to
Risk	Team, Victim
Structure	Risk, Team, Victim
Victim	Risk, Team, Structure
Team	Risk, Structure, Equipment
Vehicle	Team, Equipment
Equipment	Team, Vehicle

There is no important relationship between the Facility entity and the other entities to the commander's analysis.

The interface, shown in Figure 6, was designed to be simple and easy to use. Intuitive icons were utilized to enhance the speed of the comprehension.

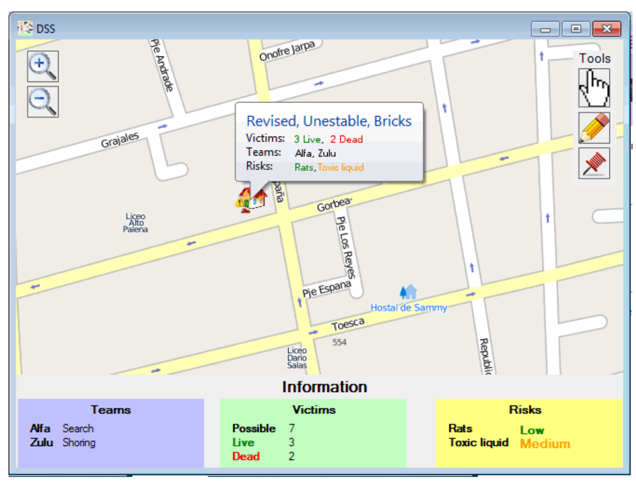

Figure 6. Information is shown in squares at the bottom of the screen

In this image, a map, a set of tools and squares of additional information are displayed. The map is broken into tiles which can be dragged with the "hand" tool. The "pencil" tool allows the user to draw and create annotations directly on the map and the “lens” tool allows zoom in and out. Beyond these tools, the Points of Interest (POI) activated by the user are shown in its respective location (for instance, a house). Some useful information about the POI is also displayed in a balloon. Additional information can be visualized in the squares at the bottom of the screen. This strategy aims to avoid hiding other important objects with a great balloon.

Another important feature for the command, shown in Figure 7, is the alarm message. Information classified as high priority can be displayed even without being demanded by the user. These messages can be about new high risks or about victims found.

Figure 7. Alarm message triggered by a new high risk

V. Methodology

As a first step of this work, a survey in literature and interviews with officers from 1^{st} and 2^{nd} Firefighters Companies from Santiago, Chile, were done aiming to collect data and, as a result, was developed a conceptual model that organizes information into seven major categories and sets their relationships. The definition of these relationships also revealed heuristics used by experienced commanders in emergency situations.

The work has progressed with the application of some deeper interviews and Cognitive Task Analysis (CTA) methods, but at this time with officers from Brazilian Fire Department, aiming to collect the main objectives and decisions made in emergency situations, beyond more specific heuristics. This tacit knowledge composed the information priority layer model presented in Figure 5. Below is explained how were applied each of the methods mentioned.

Perhaps one of the most commonly used methods in CTA, the structured interview has as its main feature the efficiency in achieving the goals aimed. It is also an excellent way to supplement the data obtained by other methods, for example, observation or automatic capture. However, it collides in the disadvantage of depending on skills that go beyond collecting and analyzing data of the interviewers. The first structured interviews were undertaken with the assistance of a non-functional prototype system in order to gain the trust of respondents and mainly illustrate the application scenario. As a result, we obtained the categories of information and its data.

The Twenty Questions method consists in creating a scenario that is presented with only limited information to the interviewee. The interviewee should make 20 questions that lead him to be aware of what is occurring in the hypothetical situation. This technique was applied in order to discover the main goals of the command in the assessment of a situation. Knowing these objectives, it becomes easier to drive respondents to derive the decisions taken during emergencies.

Another CTA technique applied to collect the heuristics used in the decisions was the Storytelling. This technique has been identified as an effective way to capture the tacit knowledge that is difficult to be formally externalized. Through this technique it was possible to capture heuristics that are used implicitly in decision making.

These heuristics were included in the knowledge combination scheme, shown in Figure 4, to create the information layers available to the commander.

VI. Conclusions

In this article we discussed the needs and requirements for implementation of a decision support system in a command post for medium-sized urban emergency situations.

The first requirement stated deals with the mobility of both the rescuers and the commander, considering that command posts are usually set in front of the entrance of the emergency and can be mounted either in tents with tables and chairs or in the hood of vehicles.

Secondly, it was discussed the need for local communication to be independent of fixed assets that may not be available. Information is transmitted through this communication channel from mobile devices, carried by first responders, to the command decision support system.

For long-distance communication it is often proposed in the literature the use of satellites. However, in this work we proposed the use of GSM network, which can be an economically viable alternative to emergency response organizations in Latin America, which are based on voluntary activity.

The third aspect considered relates to how work is actually done at the command post. For this purpose, Cognitive Task Analysis techniques were used, which are capable of capturing the tacit knowledge of commanders. The focus for the implementation of a DSS is to avoid cognitive overload, but without neglecting information for decision making.

Therefore, a data relationship model and information display patterns were determined based on user needs at each moment. These models and patterns aim to present the information grouped and on demand.

These models were validated by experts, but it is still necessary to conduct experiments to prove their effectiveness during times of stress and pressure experienced in an emergency situation. The realization of such experiments is not trivial, considering that in this type of situation, human lives are in danger and any delay or error in a decision could lead to tragic results. On the other hand, simulated events are not able to generate the emotional charge experienced in real situations, which can cause a bias in the evaluation of the system.

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