Development of a Mobile Situation Awareness Tool Supporting Disaster Recovery of Business Operations

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Situation awareness is deemed essential whenever tackling situations characterized by complexity, hard to define causal relationships, dynamic changes and lack of information. This paper describes the development of a model and tool supporting collaborative construction of situation awareness. The proposed model organizes awareness information elements according to situation dimensions, dimensional elements and correlations between dimensional elements. The approach provides a strategic view of the situation and a structure supporting concurrent information updates. The developed tool supports collaborative information management using mobile devices and pen-based interaction. The paper also reports a case study employing the model and tool in the support to disaster recovery of business operations. The adopted research approach is exploratory and theory-driven. The evaluation task adopted the inspection method, employing experts in critical infrastructures maintenance. The obtained results indicate the model and tool are adequate to the types of disruptive events faced by critical infrastructures maintenance teams. The obtained results also indicate the proposed model and tool are regarded as mostly important to less experienced members; and also fundamental to develop emergency plans.

Keywords: Collaborative Situation Awareness, Disaster Recovery, Mobility Support, Decision Support Systems.

1. Introduction

The Cynefin framework has been developed with the purpose to understand the impact of complexity on organizational decision-making (Snowden and Boone 2007). This framework distinguishes four main decision-making contexts: simple, complicated, complex and chaotic. Stable and straightforward relationships between causes and effects characterize the simple context. In these circumstances, the most adequate decision-making strategy is selecting an available plan. The complicated context is associated with multiple right answers for a known, albeit difficult, problem. Experts are necessary to analyze the concrete situation, find out the relationships between causes and effects, and develop a response plan.

The complex context deals with unpredictable and emergent situations where relationships between causes and effects are neither predefined nor easily analyzable. Thus the best decision-making strategy consists in probing the system, obtaining feedback and then deciding the most adequate course of action. The chaotic context is mainly characterized by turbulence, where the relationships between causes and effects may be unstable. The best decision-making strategy in this context recommends acting first and analyzing the consequences later.

The simple and complicated contexts are associated with an ordered world and rational decision-making. On the contrary, the complex and chaotic contexts concern the lack of order in the world. Of course we may find out many organizations operating mainly in one side of the world. The governmental bureaucracy would be exemplary of the simple, stable and highly standardized context. But most organizations actually must deal with both worlds in order to maximize their chances of survivability.

One major challenge associated with shifting the operations towards the unordered world concerns a cognitive function named Situation Awareness (SA). SA may be loosely defined as knowing what is going on in the operating environment (Endsley 1995), dealing with a large amount of sensory cues to ultimately perceive what is important to the task at hand and how it may be effectively performed. SA is always associated with rich and dynamic environments such as piloting, air traffic control and surgical operations. SA may be structured in three cognitive steps (Endsley 1995; Endsley 2003): (1)

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monitoring the contextual elements available in the environment; (2) diagnosing their meaning; and (3) projecting their near future consequences.

SA may elucidate the cause-effect relationships established by the unordered world posited by the Cynefin framework. SA is crucial to explore a complex context, since it serves to launch probes and perceive their effects in the environment, while building a conceptual map of the situation. SA also supports the operations in a chaotic context, allowing proactively building patterns of reasonable action based on reflection over anticipated actions.

We emphasize that SA is both an individual and collaborative function, since very often multiple operators are necessary to disentangle asymmetric information. Therefore, besides the three cognitive steps mentioned above, we should also consider the interactions necessary to adjust individual and collective knowledge, sharing situation information and anticipating the information needs of others (Shu and Futura 2005).

We seek to investigate how information technology may support collaborative SA. And we have a particular interest in one specific type of information technology: mobile devices such as personal digital assistants, mobile phones and tablet computers. Mobile technology has seen a rapid development in the last few years. Following the Moore's Law (Moore 1965), the computing power is increasing rapidly, prices are decreasing, physical dimensions are becoming more adequate to mobile use and popularity is increasing. The development of networking and middleware technology supporting wireless communication, information synchronization and location awareness is also promoting the wide adoption of mobile technology in collaborative settings (Baloian, Zurita et al. 2007).

People have now the prospect to work and collaborate everywhere, wandering in office buildings, visiting clients, commuting from home to office, staying at home and of course vacationing. Furthermore, by shifting the operations towards the unordered world, we are also finding very compelling application scenarios in which mobile technology may be critical to develop SA:

- In hospital environments, supporting a constant flow of information about patients' status amid healthcare personnel (Muñoz, Rodriguez et al. 2003; Tentori and Favela 2008);
- Beyond that, mediating healthcare information while being outside the hospital premises, considering both healthcare personnel and patients (Sá, Carriço et al. 2007);
- Facilitating fieldwork and remote access to experts operating in remote areas (MacEachren 2005; Antunes and André 2006; Ochoa, Pino et al. 2008);
- Supporting rescue efforts and emergency management in disaster areas (Cai, MacEachren et al. 2005; Kwan and Lee 2005; Monares, Ochoa et al. 2009).

This paper reports exploratory research aiming to develop a SA tool on top of mobile technology. The specific application area is Disaster Recovery (DR) of business operations. In this context, the main goal of DR is preventing, mitigating and containing the occurrence of major disruptions in critical business infrastructures, including networking, databases and distributed services. The interest in DR has significantly increased since the occurrence of major business breakdowns in the United States of America derived from the terrorist attacks on the Twin Towers and hurricane Katrina (Hiles 2008).

The case reported in this paper describes the initial trials of the SA tool in two organizations. We describe the preliminary study, requirements elicitation and evaluation feedback obtained from the trials.

In the next section we overview the related work. Section 3 describes the adopted research methodology. The SA model and tool are described in Sections 4 and 5, respectively. The case study is presented in Section 6. The findings from the case study are presented in Section 7. Section 8 discusses the research outcomes and presents some concluding remarks.

2. Related Work

A wide number of situations may lead to lack of order in business operations, some emerging from inside the organization (e.g., latent problems, failure of key resources, lack of flexibility and the need to innovate) and many others emerging from the environment (e.g., market dynamics and natural hazards).

DR emerges as an organizational reaction to these situations. A simplified view of DR would consider the separation between disruptive and normal operations and the objective to move the operations from the disruptive towards the normal situation. DR is a complex process. It is affected by surprise, real-time constraints, spatial extension, number of involved stakeholders, risk and uncertainty, limitations of human perception and cascading events (Wybo and Latiers 2006).

Of course technology has always been considered a silver bullet capable to help resolving most organizational problems (Grint and Woolgar 1997). It is therefore natural that significant research effort has been applied developing technology support for DR. But the complexity associated with DR challenges Information Systems Development (ISD), mostly because the analysis and design activities may not realistically cover all the possible events, contexts and dynamic interactions that may occur (Perrow 1999; Turoff, Chumer et al. 2004).

This challenge is patent when we consider ISD of work processes. We define work models with the objectives to automate recurrent activities and improve coordination and efficiency. But the support to unexpected exceptions, incomplete procedures and dynamic changes is highly problematic (Mourão and Antunes 2007).

Markus et al (2002) defend that a new approach to ISD is necessary to address the new class of systems falling outside what we previously referred as the ordered world. This new class of systems is fundamentally characterized by being flexible, context dependent, distributed, dynamically evolving and collaborative. High Reliability Organizations (HRO), such as aviation and nuclear operations, clearly emphasize these characteristics (Weick and Sutcliffe 2001).

Interestingly, collaboration is regarded a fundamental asset in HRO (Baker, Day et al. 2006). In complex and chaotic situations, the complete reliance on anticipated plans is quite difficult or even impossible (Bruinsma and Hoog 2006). Therefore, the involved participants must orchestrate their interventions while adapting to the unfolding events. Their decisions may lack full insight about the situation context. Information shortage, as well as information overload, may lead to initial unbalanced responses (e.g., prioritizing less urgent actions) and mutual adjustments. Other factors emphasizing the role of collaboration in complex and chaotic situations include the spatial extension of the situation, perception and knowledge gaps among the involved actors and poor overall SA and representation (Wybo and Latiers 2006).

SA is a key concept to understand the impact of collaboration on DR, mostly because SA is an antecedent of sensemaking, collaboration and collaborative decision making (Weick 1995; Weick 2001). Businesses have a strong cognitive and heuristic character (Möller 2009) that must be necessarily supported with SA.

Based on a synthesis of 15 definitions found in the literature, Salmon et al (2007) define *individual SA* as the continuous extraction of environmental information and integration with previous knowledge to form a coherent mental picture and using that picture to direct and anticipate future events.

Since the late 1980s, a number of SA models have been proposed. The Ensdley's three-levels model is the one that has received most attention (1995). In level 1, training and experience directs attention to critical elements in the environment. Level 2 integrates elements that aid understanding the meaning of critical elements. And level 3 considers understanding the possible future scenarios.

Bedny and Meister (1999) rooted their model on activity theory and offer a more dynamic perspective over SA, considering a continuous loop on which SA directs the interactions with the world, which in turn modify SA. This continuous loop is motivated by the disparity between the one's goals and the current perceived situation. It comprises three stages: orientational (development of an internal conceptual model), executive (moving towards a desired goal via decision-making and action execution), and evaluative (assessing the feedback information and influencing the other stages).

Smith and Hancock (1995) proposed an ecological view of SA. The theory is that SA is neither resident in individuals nor in the world but rather in the interactions that are motivated by one's schemata; and that the outcome of that interaction will modify the existing schemata, which in turn directs further exploration.

All of the above models consider individual SA. The notion of *team SA* is more recent and currently lacks a universally accepted model (Salmon, Stanton et al. 2007). Some literature on team cognition has been exploring the idea that team effectiveness may not only depend on an overlap of individual cognitions but also the construction of team cognition (Hayes 2006). Team SA combines individual SA (necessary to conduct individual tasks) with shared understanding of the situation among team members (Endsley and Jones 2001). Shu and Futura (2005) posit that team SA is collaborative and partially shared and partially distributed. Additionally, Salas et al (1995) and Fiori et al (2003) highlight the importance of team processes as contributors to team SA, compensating the limitations of individual SA with information exchange and communication.

Stanton et al (2006) suggest that in complex contexts individuals rarely perform entirely independent activities. They are often coupled and tend to be coordinated. This focus on coordination changes the unit of analysis and affords analyzing interactions at many different organizational levels. Thus collaborative SA comprises individual SA, distributed SA, shared SA and team SA. This multi-dimensional view posits many challenges to SA research and development.

3. Research Methodology

This work assumes an engineering viewpoint aiming to improve collaborative SA through technology development. But the emphasis on cognition and collaboration mandate a user-centered approach to technology development. Therefore, in order to bring together these two different perspectives, we adopted a research methodology combining exploratory with theory-based research.

In the one hand, the exploratory perspective seeks to obtain qualitative insights about the construction and maintenance of SA. This requires a strong focus on understanding the users' behavior within a specific working context, which in our case is maintaining business operations after major breakdowns in technological infrastructures. The case study method (Gerring 2007) was selected to gather contextualized information from people highly experienced with DR of business operations.

In the other hand, our focus on technology development also mandates a positivistic approach to supporting SA in the selected application context and using a particular technological solution. Therefore, the theory-based approach (Briggs 2006) was adopted to ground the technology development in a sound engineering basis.

Consequently, the case study discussed in this paper is also directed towards validating the SA model and tool we have been developing. As Briggs (2006) points out, a good theory can drive non-intuitive design choices that improve technology outcomes.

Because of this twofold approach the adopted case study research is expected to provide hybrid outcomes. Being theory-driven, the outcomes are less open to surprise and the contextual information is less varied and insightful than usual. By also being exploratory, a rigorous validation of the proposed SA model is also less important than usual. Overall, the adopted research methodology seeks an early validation of the theoretical and practical constructs put forward regarding the use of mobile technology in the support to collaborative SA. The defined research plan has the following major steps:

1. Develop SA theory and model;
2. Implement the SA theory and model in a computational tool;
3. Study the acceptance of theory and tool by practitioners;
4. Go back to 1 until practitioners are satisfied.

4. Situation Awareness Model

Our SA model proposes a representation of the key information elements involved in the DR process. We were inspired by the "Swiss cheese" model (Reason 1997; Reason 2008) to organize the SA information elements. The "Swiss cheese" model posits that for an accident to occur an alignment of holes in different defense layers must occur.

We may characterize these defense layers according to a continuum of organizational strategies ranging from the sharp-end to the blunt-end (Hollnagel 2004; Woods and Hollnagel 2006). At the sharp-end we have operators and practitioners, the first line of defense we usually find in a complex system. Towards the blunt-end we may find line managers, administrative controls and regulations, designers and engineers, policy makers, and a myriad of other organizational factors and agents that indirectly contribute to the defense system.

Although the actual events that may lead to accidents tend to be highly intertwined and interdependent, the sharp-end-blunt-end view offers a simple way to conceptualize complex accident trajectories in a simple and linear way. We defend that this type of strategy may as well be adopted to construct SA. The main reasoning is the actors involved in DR may consider different SA layers in a way very similar to the one adopted by the "Swiss cheese" model. More specifically, our model defines a layered arrangement of the SA elements involved in the DR process, aligned from the sharp-end to the blunt-end.

Furthermore, we also adopt the perspective that information display is fundamental to support information analysis. We find in the literature many different forms to display qualitative data (e.g., concept clusters, empirical clusters, checklist matrixes, timelines, event listings, causal networks and cognitive maps

(Miles and Huberman 1994)).

One way to display awareness information is using Situation Matrixes (SM), allowing establishing correlations between several elements aligned according to dimensions of the situation. One typical SM is the goals/actions matrix, which correlates the defined goals with the actions perceived as necessary to accomplish those goals. Other examples of SM may include time/events, events/conditions, problems/solutions, actions/actors and actors/resources. Observe three SM examples in Figure 1.

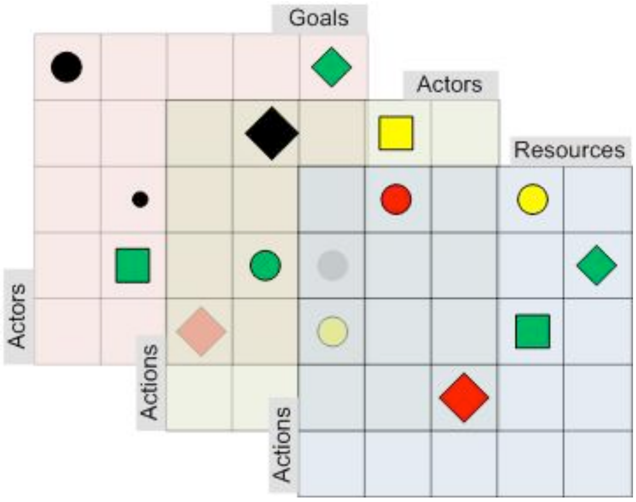

Figure 1. Examples of Situation Matrixes. The correlations are represented with symbols.

We hypothesize that the combination of sharp-end-blunt-end layers with SM offers the structure necessary to build and visualize SA. In the one hand, the layered matrixes provide a strategic view of the situation, based on the dimensions perceived as necessary to understand the situation and act upon it. In the other hand, the correlations within each matrix provide a tactical view of the situation in its multiple dimensions. The proposed SA model is illustrated in Figure 2.

Of course this SA model should be understood in a dynamic way. For a given application domain, an initial set of dimensions and SM may be available to support initial sensemaking, decision-making, planning and action. But, as the situation evolves, new dimensions and SM may emerge in real time, while others may lose importance and disappear. We finally note the proposed SA model should be collaboratively managed. More details about this functionality will be presented in the next section.

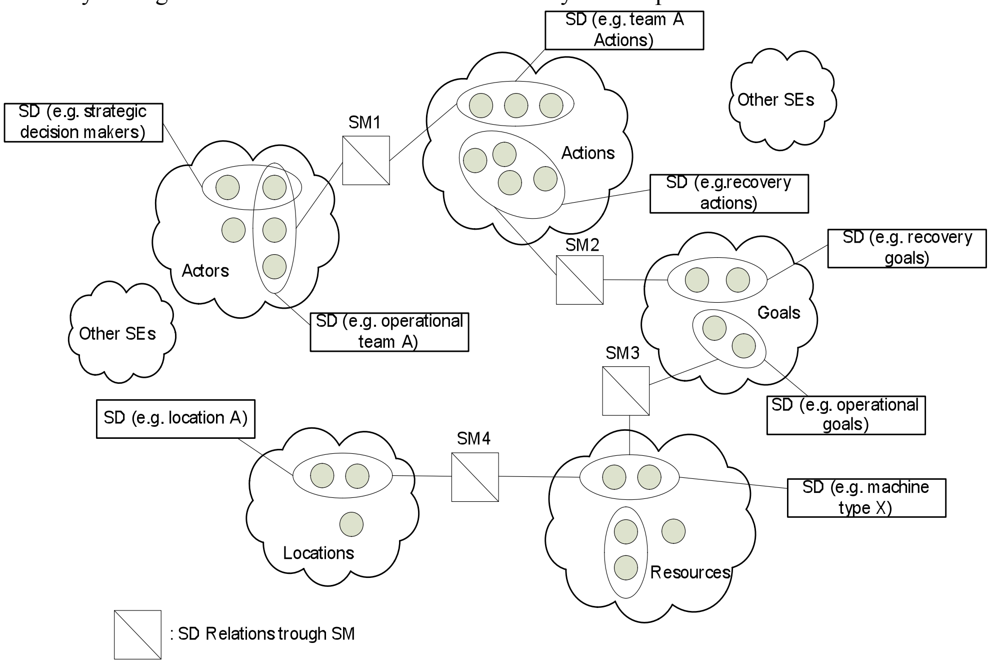

Figure 2. Situation awareness model.

5. Situation Awareness Tool

According to the proposed SA model, SA is structured with a collection of SM aligning the various dimensions of the situation, including events, conditions, goals, resources and actions. Let us start by describing the SA model in more detail.

The SM have two dimensions. Each dimension includes several entities that may by relevant to assess the situation. For instance, the goals dimension may include entities like mitigation, preparedness, response and recovery. We note that in this case there is a sequence relationship between the entities that reproduces typical emergency handling stages (Harrald and Stoddard 1998). Another dimension may consider the actors involved in the disaster recovery process, a case where there may be no definite type of relationship between the entities. Therefore, the proposed tool should not define a priori the type of relationships between the elements defined for a dimension.

Regarding the SM correlations, their purpose is to express the strength of the relationships that contribute to assess the problem and delineate the solution. For instance, considering a SM with Goals and Actions, the correlations may express how much some actions contribute to some goals. The correlations should follow an ordinal scale (e.g., none, some, low and high). But again the semantics depends on the specific application domain. What is fundamental is the correlations should be expressed through different visual symbols (and attributes like color) and convey an overall perspective of the several relationships established in a SM.

Of course several SM are necessary to perceive the whole situation context. These SM are organized in a tree, a structure that is adequate to model the various dimensions of the situation (including time). Again, the relationships between the several SM are application dependent. In some cases, they may follow the sharp-end-blunt-end relationship previously discussed. In other cases they may closely follow chains of events, different levels of perception, projections of future events, or even a combination of the above. Therefore, the implementation must be independent from any specific application domain but at the same time be flexible enough to accommodate the various configurations previously mentioned.

The developed tool supports the manipulation of SM using pen-based gestures. Interaction with the SM is done in real time and using a small number of pen-based gestures. The gesture shown in Figure 3.a creates a new SM. The list of available dimensions is displayed when pointing towards the right side of the display, as shown in Figure 3.b. As illustrated in Figure 3.c, the selected dimensions may be dragged to the SM using the pen. Note again that currently the SM are bi-dimensional. Figure 4 shows a SM with two dimensions, actors and actions.

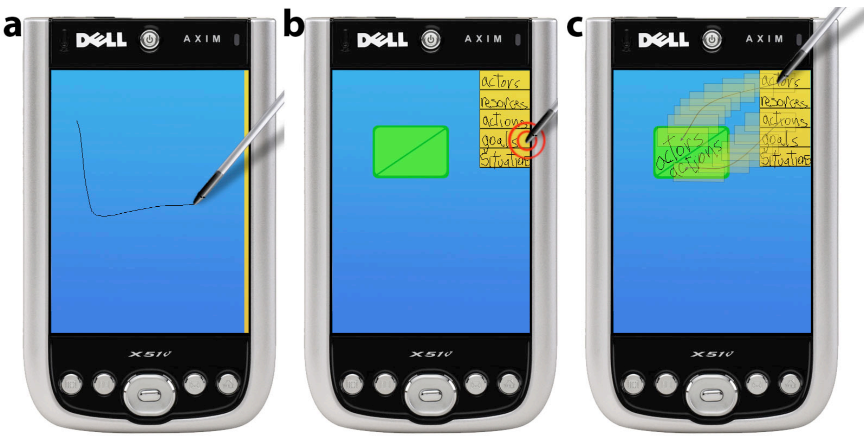

Figure 3: Creating Situation Matrixes: a) creation; b) displaying dimensions; and c) assigning dimensions.

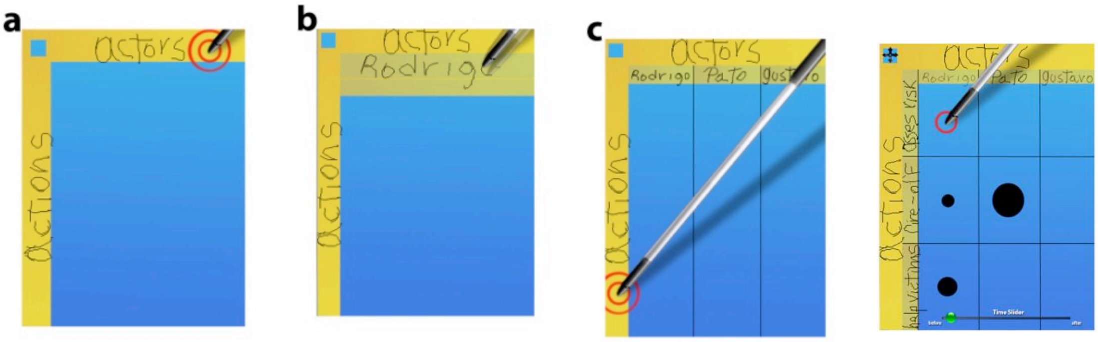

Figure 4: Populating Situation Matrixes: a) creating dimensional entities; b) and c) naming dimensional entities; and d) defining correlations in the SM.

After assigning dimensions to a SM, the users may start populating it with dimensional entities. One example is defining several actions and actors. This is accomplished by inserting lines and columns in the SM. To create lines and columns, the user has to double click on the label (see Figures 4.a and 4.c). After this, the user should name the dimensional element. Figure 4.b shows how the "Actors" dimension is populated with the "Rodriguez" element.

Figure 4.d illustrates how correlations are established. The tool allows selecting correlations from a list of predefined values. We have currently implemented four correlation values: (a) empty cell, no importance given; (b) small dot, small importance; c) medium dot, relative importance; and (d) big circle, high importance. Clicking on a cell will cause a pop-up menu to be displayed with the available options.

Since users may be interested in viewing different parts of the SM according to their context of action, the system allows hiding rows or columns by clicking on the respective label. Hidden rows and columns are displayed with thick lines. To show again a hidden column or row, the user just has to double click on the thick line.

Still regarding SM visualization, the tool supports left-right and up-down scrolling, combined with zoom-in and zoom-out. These interactions are illustrated in Figure 5. Note that, since display space in mobile devices is rather scarce, the above navigational capabilities rely on gestures instead of typical visual elements such as scrollbars.

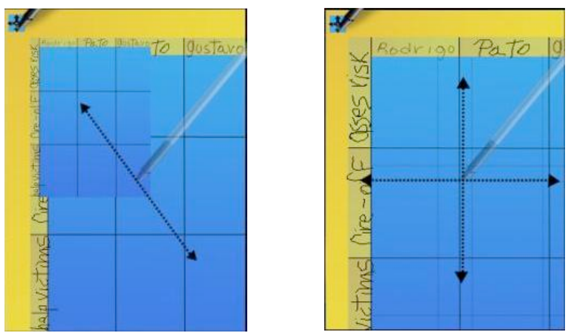

Figure 5: SM Navigation: a) zoom-in and zoom-out; and b) left-right and up-down scrolling.

We also note the mobile devices we have been using are capable to display one single SM, and with limitations, since only a small number of dimensional elements may effectively be displayed without scrolling. The implemented interaction mechanism for navigating multiple SM is the hierarchical menu.

The SA tool adopts a fully replicated information architecture and supports concurrent updates of the SA model. Every mobile device maintains a replica of the SM tree and synchronizes the updates whenever the network connection may be established. The users can thus modify or update the SM tree at every time, independently of the other users and the network connectivity. The adopted concurrency management approach has been coined "open floor" by the Computer Supported Collaborative Work (CSCW) community (Lauwers and Lantz 1990; Reinhard, Schweitzer et al. 1994). This approach does not define any rules governing the concurrent updates to shared information, delegating to the users any necessary social arrangements, which should be constructed during training.

The functionality described above was implemented on top of an existing mobile collaborative platform (Baloian et al. 2007). This platform has already been used to develop several mobile applications (e.g., (Zurita and Baloian 2005; Zurita, Antunes et al. 2007)). The platform relies on ad-hoc networking to maintain collaboration under situations where structured networking infrastructures may fail, a characteristic that is particularly adequate to the disaster recovery context discussed in this paper. More technical details about the mobile collaborative platform may be found in (Zurita, Baloian et al. 2008; Baloian and Zurita 2009).

6. Case Study

6.1 Definition

The case study concerns the support to DR in two information technology departments operating in two different organizations. These two departments shall be considered homogeneous for the purposes of the study.

The main responsibilities assigned to the selected departments include: installing and maintaining the networking and computing infrastructures, including network appliances, computers, printers, servers, backup units, etc; controlling the security threats to this infrastructure; and ensuring business continuity.

A large amount of the work accomplished by these departments concerns highly standardized activities, such as reconfiguring routers, updating virus-scanning utilities, monitoring service levels and responding to requests from single users and other departments. Our focus is not on these standardized activities but instead on the non-routine activities necessary to maintain business continuity under abnormal conditions. These non-routine activities are not solicited very often, but are highly pressed by time constraints and cognitive workload. This includes handling server failures, critical service failures (mail, web proxy, domain naming) and large-scale networking failures, not forgetting recovering from accidents such as fires, floods and earthquakes.

Despite the existence of highly trained personnel, standardized business continuity plans and detailed procedures to address some disruptive situations, three main issues may strongly condition their effectiveness. Firstly, we should consider that standard procedures typically do not accommodate the whole variety of contextual and contingent factors affecting DR operations. Therefore, established plans and procedures serve more as information resources than actual operational processes (Suchman 1987). They may be one important asset but are not as critical as other assets, in particular highly knowledgeable human resources. Secondly, many DR operations require tacit knowledge, experience, decision-making and collaboration when assessing the situation and developing creative solutions and temporary workarounds. And thirdly, we should also consider the operation of large information technology infrastructures is typically distributed in two dimensions: spatially, regarding the various offices, buildings, cable networks and technical spaces; and cognitively, since knowledge and skills tend to be evenly distributed. This distributed nature emphasizes the potential demand for collaborative SA.

What mobile technology may bring to these scenarios is empowering team members with collaborative SA. The envisioned functionality includes group communication and information sharing, synchronization and visualization. More specifically, considering the defined SA model, the proposed functionality includes sharing the SM, allowing team members to collaboratively create, view and update SM and their correlations in real time and on the move.

Based on the above premises, the main objective of the case study is exploring how the selected information technology departments may utilize mobile technology to recover from abnormal infrastructural conditions. The main factor of interest is SA.

6.2 Preliminary study

To gain insights about DR of business operations, to verify our assertions and to consolidate our goals, we conducted a preliminary study with the participating teams. The concrete objectives defined for the preliminary study were to (1) identify the types of incidents that emerge in these organizations and (2) the practices developed by the teams to overcome them. The participating teams were composed by: one coordinator, two senior technicians and two junior technicians; and one coordinator, one senior technician and one junior technician.

Semi-structured group interviews were adopted. The following open questions guided the interviews:

- Which situations may be described as incidents/accidents?
- Which preventive and diagnosis practices are currently being used?
- Which formal and informal procedures have been adopted?
- Which communication mechanisms are used during disaster recovery?
- Do you use any performance metrics?
- Do you use any plans with disaster recovery procedures?

The outcomes from the semi-structured interviews indicate the most critical incidents are related with server failures, mostly due to disk failures, and connectivity losses in specific network segments compromising a wide variety of services. A preoccupation with more untypical problems was also reported, "[...] like a flood in the basement where some of the equipment is located [...]"

As pointed out by both teams, the existing preventive practices rely heavily in monitoring active network components through control panels, where alerts are displayed and emailed to the technicians. Many critical situations require the team members find out where the failing components are physically located. And they have to go to the physical locations to perceive the actual situation context. The diagnosis and recovery practices rely heavily in the field experience of each team member, which seems to be highly specialized, e.g., there are Windows, Mac and LINUX specialists. The teams rely on quick informal meetings, phone calls and chat-tools to share knowledge, coordinate activities and make decisions. Besides performing maintenance actions, the teams also rely on service level agreements with suppliers and a spare stock to overcome problems.

One key concern that emerged from the semi-structured interviews is that teams find it important to document what has been done to diagnose and recover from incidents and accidents. This information was considered essential to support organizational learning, especially because human resources tend to rotate a lot in these units and thus past experience is often lost.

Although both teams use Trouble Ticket software in their routine maintenance operations, they also realized that Trouble Tickets are almost irrelevant during non-routine situations. Trouble Tickets are sometimes used for incident opening and only occasionally for post mortem annotations to close incidents, with no significant impact on planning future responses.

Interestingly, one of the mentioned reasons for not using Trouble Tickets more often is they are not accessible where the incidents actually occur. The networking and computing infrastructures are distributed through several building and offices, while the Trouble Tickets are only available in desktop computers that may be inaccessible in these sites.

From the interviews we realized: (1) the selected application scenario concerns a mobile collaborative situation perceived as critical to the teams; and (2) the tasks perceived as important by the teams are related to decision making support and organizational memory.

6.3 Requirements elicitation

Having established the relevance of the selected application scenario, we proceed with a more thorough analysis of the application requirements and their alignment with the developed SA theory and tool. We adopted the following method. First, we compiled a list of requirements from the related literature. We then requested the team members to analyze and prioritize the requirements according to their work context. And we finally established the list of requirements according to the perceived priorities.

Table 1. Requirements list.

#	Requirement	Area
1	Communication support through shared artifacts	Collaboration support
2	Transition between individual and team work	

3	Facilitate situation monitoring	
4	Minimum overhead	
5	Mobility support	
6	Help understanding situation context	Situation awareness
7	Help perceiving who is involved	
8	Assist situation size up	
9	Assist overall situation representation	
10	Knowledge externalization	Knowledge management
11	Knowledge transfer	
12	Document incident handling	
13	Improve diagnosis time	Performance
14	Improve recovery time	
15	Increase number of incidents simultaneously attended	

The requirements compiled from the research literature consider four categories: collaborative technology (Steves, Morse et al. 2001), knowledge management (Vizcaíno, Martinez et al. 2005), team performance (Baeza-Yates and Pino 2006) and SA (Salmon, Stanton et al. 2005). The first category addresses the main technological features necessary to provide collaboration support. The knowledge-management category was selected because it has already been pointed out as important in the preliminary study. Team performance concerns the efficiency of technology support. And the last category was selected to specifically address the theoretical concerns associated with SA (Endsley 1995; Endsley 2003).

In Table 1 we present the compiled requirements list that was delivered to the participants for prioritization. The participants (7 persons) were requested to individually rate the selected requirements according to relevance to the teams' work context. The ratings scale was: 1 – Not perceived as important; 2 – Less important; 3 – Important; and 4 – Very important. The answers were received by email. The consolidated scores are shown in Table 2.

Table 2. Requirements priorities.

#	1	2	3	4	AVG	STDEV
4			1	6	3.86	0.38
5			2	5	3.71	0.49
6			2	5	3.71	0.49
13			2	4	3.67	0.52
12		1	2	3	3.33	0.82
8			5	2	3.29	0.49
3			6	1	3.14	0.38
10		2	4	1	2.86	0.69
11		3	2	2	2.86	0.90
15	1		5	1	2.86	0.90
1		2	5		2.71	0.49
9		2	5		2.71	0.49
14		2	5		2.71	0.49
7		4	3		2.43	0.53
2		5	2		2.29	0.49

We defined a threshold of 3.0 for cutting off the less important requirements. As we may observe, the members rated eight requirements above the threshold (important or very important) and seven requirements below the threshold (less or not important). Interestingly, the four requirements categories are all evenly represented, although we find a slight advantage given to collaboration support and SA.

The obtained results clearly emphasize the importance given by the teams to immediacy of action (requirements 1, 4 and 13) and responsiveness to events (requirements 3, 5, 6, 8, 13). In our view, these results express the importance of tight coupling (Perrow 1999) and actually elucidate how it may be obtained. Incident documentation was already mentioned in the semi-structured interviews and emerged again as important (requirement 12).

And finally, it should also be emphasized the teams validated the alignment between our research and their interests, especially concerning SA and mobility. Mobility was the second most rated requirement, while understanding the situation context appears in third place (although the other elements of SA were ranked lower). Overall, with this inquiry we validated our main research objectives and obtained important information necessary to adapt the tool to the target application domain and users.

6.4 Theory/tool evaluation

The evaluation of collaborative technology raises many methodological concerns that have received attention from researchers in the CSCW community (Herskovic, Pino et al. 2007). Different evaluation techniques may be adopted according to emphasis on technical (e.g., interoperability), human (e.g., usability) and organizational (e.g., effects on task performance) issues (Gauducheau, Soulier et al. 2005; Vyhmeister, Mondelo et al. 2006).

An evaluation strategy well adapted to case studies and complex collaborative settings uses field methods in actual working environments (Hughes, King et al. 1994). Although this approach allows capturing very rich data, it is also difficult to accomplish for various reasons: large amount of time investment, must use a fully working prototype, requires high commitment from the organization, and also requires access to actual or simulated disaster situations.

Inspection techniques (Nielsen 1994) may also be employed in case studies. Inspection techniques rely on domain experts to analyze the technology and expose possible problems and drawbacks of technology use. Inspection techniques are less costly than field methods and may be used earlier and more frequently in the development cycle.

Steves et al (2001) defend that inspection techniques should be employed in early development stages, when prototypes are still immature, and field methods should be employed afterwards. Based on this perspective, our evaluation approach was based on inspection.

The evaluation process evolved in the following way. First, we requested the teams' leaders to develop a common use scenario. Use scenarios have been employed in conjunction with inspection techniques to bring more context to the evaluation task (Carroll 2000; Haynes, Purao et al. 2004). The developed scenario is shown in Figure 6.a.

We then conducted workshops with the teams, requesting them to inspect the tool in the context of the predefined scenario. Three interconnected devices purposely configured for the specific evaluation teams were supplied. The teams were given sufficient time to experience the tool and discuss its implications to their work. They were able to create SM, create dimensions and dimensional entities, define correlations and navigate through the various SM, observing how the various devices use the ad-hoc network to synchronize information. The teams also had the opportunity to experience the collaborative nature of the tool, supporting concurrent updates to correlations. In Figure 6.b we show the tool running on one mobile device during the workshops.

Scenario

"From several rooms, we received reports of network connectivity losses. Some technicians were notified by email, while others received several complaints by phone. The senior technician that received some of these complaints suspects the central switch located in the main building."

How the proposed tool may help diagnosing, planning and coordinating recovery actions?

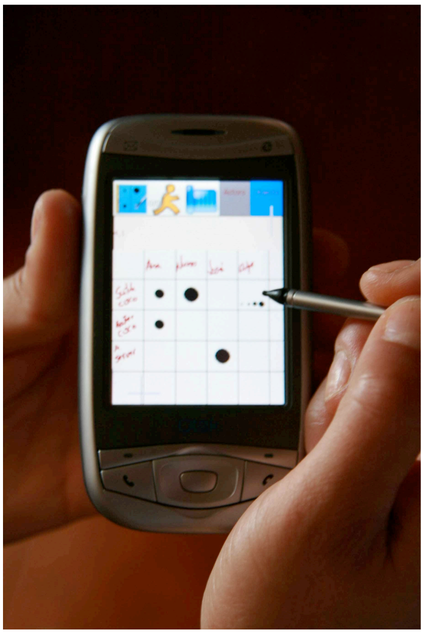

Figure 6. Inspection: a) scenario; and b) tool.

From these workshops we obtained qualitative data consisting of comments and suggestions. They revealed that when a non-routine situation occurs the personal experience of the involved operators strongly influences team SA. I.e., when highly experienced operators happen to be available during the problematic situation, it is easier to collectively understand the causes, implications and consequences of the event. The tool was perceived as most relevant to establish collaborative SA when the less experienced operators are confronted with the situation. Knowledge transfer and incident documentation was considered very important to the team leaders, while knowledge representation and externalization was revealed as most important to junior technicians.

The workshop participants also analyzed the SA model and its impact on the DR strategy. From the discussions that took place in both workshops, the highly informal and unstructured work practices were obvious to both teams. The courses of action vary according to the involved actors and some discussions took place on the more efficient ways to address various occurrences. The participants drafted several SM in paper prototypes expressing the best ways to address some incidents. Figure 7 shows some examples of these paper prototypes.

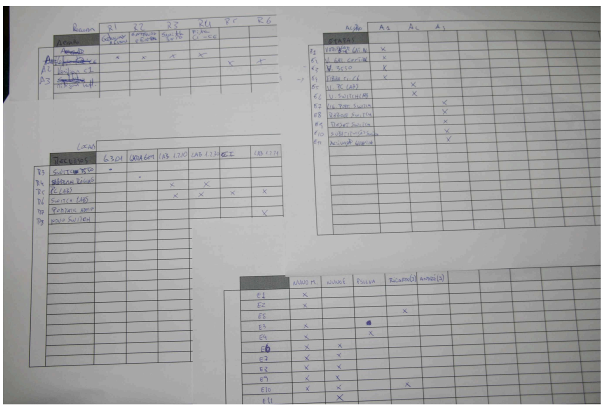

Figure 7. Situation matrixes drafted during the workshops.

This way the teams defined the set of SM most adequate to their work context. The dimensions they considered more relevant were: equipment, actors, locations, actions and steps. These dimensions would then be correlated in the following SM:

- Actions-Steps, detailing operational activities (e.g., check router X, reboot switch Y);
- Actors-Steps, defining responsibilities;
- Equipment-Actors, expressing who is responsible for the equipment (e.g., who may activate a supplier warranty and who has the skills necessary to inspect a LINUX server).
- Equipment-Locations, allowing junior team members to find out the equipment locations (e.g., main gateway of building C6 is located in room 6.3.0.1).

Of course the team members discussed a large set of usability problems they found in the tool. They recommended the SM should be easily reused across multiple DR processes. They also considered important having an overview of the whole situation, displaying all of the SM and existing correlations, something that is quite difficult to accomplish considering the small display size of the used devices.

A better support to navigating the SM was highly recommended. The participants also regarded a major challenge the maintenance of awareness information up to date, emphasizing the potential problems of having "aged" information and overhead introducing timely information in the tool. The participants suggested asking the validity of correlations: as correlations age, the users could be prompted to report their validity; they also suggested using visualization techniques to express the aging of correlations. And finally, both teams pointed the proposed model was aligned with the requirements they considered relevant for DR of business operations.

6.5 Results from the case study

It was possible to confirm with the case study that SA is influential whenever the teams must coordinate non-standard activities, since activities are distributed throughout the physical space and expertise is evenly distributed. SA seems to be more important to inexperienced workers.

By the end of the workshops, both teams reported the evaluation sessions revealed something they were only suspicious about: the individuals' experience strongly conditions the team's performance. The issue was not completely new to them, and they were trying to address it by compiling contingency plans externalizing and optimizing such knowledge. But due to lack of time, they have given low priority to this goal and so the available list of contingency plans is short in one organization and non-existent in the other. Both teams perceived the SA tool as an opportunity to define contingency plans. Thus, one interesting outcome of this case study is that, unlike what we were expecting, the SA tool seems more useful to indirectly document DR strategies rather than supporting direct human interventions.

The teams' appropriation of the SA tool was patent. The workshop sessions served to define a template for contingency plans that could be used in the future. The template uses the proposed SA model and organizes the overall response according to a set of SM and dimensions, including equipment, actors, locations, actions and activities.

Finally, regarding the adopted research approach, some considerations are also worth noting. The first interview revealed crucial to establish a common ground for a richer discussion in the requirements and evaluation phases. The prototype was fundamental to develop a pragmatic view over the tools' advantages (e.g., mobility) and drawbacks (e.g., interaction problems and small display size), thus facilitating a realistic assessment of its utility. Overall, the evaluation process was adequate to an exploratory research focused on a specific theory and model, and based on expert evaluation.

7. Discussion

The main organizational problems dealing with the unordered world seem to be rooted in a lack of collective awareness about the ongoing situation, plus communication and information management problems (Kanno and Furuta 2006; McManus, Seville et al. 2007; Milis and Walle 2007). Therefore we regard increasing the level of collaborative SA a fundamental requirement for DR. The teams that participated in our research supported this view.

To accomplish this endeavor, we articulated the main information elements necessary for collaborative SA with a model. The model, which was inspired by the "Swiss-cheese" model (Reason 1997; 2008), organizes the information elements necessary for collaborative SA in a strategic view of the situation ranging from the sharp-end to the blunt-end. Each view brings together two dimensions of the problem and several correlations between the defined dimensional elements. The model may be constantly updated in runtime thus supporting information sharing, coordination and collaboration.

Events, awareness and actions are often difficult to disentangle in the unordered world. The traditional linear models (e.g., Domino model (Heinrich 1931)) of accident trajectory suggest there is some intrinsic order over time, from event to awareness and action, but the reality is that chaos is what most defines disastrous conditions (Kelly 1998). The typical approaches to DR rooted on linear models have been criticized for only distinguishing the major stages in accident trajectories (Kelly 1998), forgetting many non-linear relationships between the various elements that make up the accident context. Overall, the linear models seem to provide few insights about the actual unfolding of a disaster.

Others suggest that DR should instead focus on systemic views of the situation (Hollnagel and Woods 2005a; Hollnagel and Woods 2005b). These new approaches emphasize contextual, situated, contingencial and interactive relationships between multiple information elements. The model and tool we developed adopt the later perspective. The main objective is maintaining collaboratively and in real-time the multiple interdependencies between events, actions, actors, contexts, plans and many other factors involved in DR.

The model and tool are generic, offering a common strategy to build a shared view of the situation using situation matrixes, situation dimensions, dimensional elements and correlations. Predefined situation matrixes, situation dimensions and dimensional elements may be tailored to specific domains and facilitate the first approach to the situation. But depending on the involved organization and emergent situation, this information structure may have to be redefined in runtime. Therefore, a significant effort has been made in order to support dynamic changes to the information structure.

Another characteristic of the proposed model and tool is the support to concurrent changes to the information structure. This approach is quite distinct from others emphasizing the chain of command and control. The hierarchical control has been criticized for favoring a concentration of decision-making and putting too much emphasis on vertical communication (Drabek and McEntire 2003). Instead, several disaster sociologists emphasize that critical responses should be organized with decentralized structures and cooperation between actors (Drabek and McEntire 2003). The proposed model and tool also adopt this later view.

The preliminary results from the case study indicate the model and tool are influential whenever the teams must coordinate non-standard activities, especially when less experienced workers are involved in the process. The results also indicate the importance of constructing and maintaining organizational memory, which may be supported with the proposed tool. Nevertheless, more qualitative and quantitative experiments are necessary to assess the model/tool contributions. Our research work is currently focused on: (1) developing metrics adequate for collaborative SA, which may be employed to quantitatively assess the tool's impact on team performance; and (2) developing experimental scenarios that could be used in laboratory to qualitatively assess the teams' construction and use of the situation matrixes in disaster situations.

8. Conclusions

The scenarios characterized by complexity, hard to define causal relationships, dynamic changes and lack of information introduce important changes in organizational decision-making. Instead of predefined and structured approaches, we find strategies based on exploration, probing and acting while trying to understand the situation.

The model and tool discussed in this paper address these new strategies. The focus is on the support to the collaborative construction of situation awareness by the involved users, allowing them to dynamically and concurrently manipulate the information structure. Furthermore, the proposed model organizes the information structure according to multiple types of relationships, such as problems-solutions, causes-effects and actions-actors. This structure aims to facilitate information interaction and visualization.

The case study involved teams with high expertise in disaster recovery of business operations evaluating our model and tool. Inspection was the adopted evaluation method, which means that further research should be conducted to validate the model and tool in real disaster situations. Nevertheless, the evaluation data already obtained indicate the model and tool are capable to respond to the most significant problems faced by the teams. The participants' feedback also points out towards the need to improve information visualization and interaction in mobile devices.

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