An Emergency Response Model Toward Situational Awareness Improvement

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ABSTRACT

When facing emergency scenarios, several contingent factors may strongly condition the pre-defined response procedures. The proposed approach takes the perspective that an emergency response tool may guide the response effort. The tool adopts a conceptual model grounded on existing situation awareness models and research work done with High Reliability Organizations. The model structures the emergency management process in a set of dimensions that should be collaboratively correlated by the involved participants in order to mitigate the disruptive situation. An instantiation of the proposed approach is also described in the paper, focusing on IT service desk teams addressing emergency incidents that may compromise business continuity.

Keywords

Emergency Response Model, Situation Awareness.

INTRODUCTION

Emergency situations may be found in a number of domains. Turoff et al (2004) states that organizations may experience emergency situations in their routine contexts, like failures of key resources, supply shortages, market demands and/or changes in regulation. As so, research on emergency management may be found in several research fields, such as management, Information and Communication Technologies (ICT), sociology, political science, psychology and public administration. This multidisciplinarity may be among the causes that lead to a lack of standardization in terms and concepts. In fact, we may find in the related literature terms like crisis management, emergency management, emergency response, disasters management and incident management.

While some authors have defended the need to standardize and adopt common definitions (Boin 2004; Sujanto, Ceglowski et al. 2008), others state these differences offer valuable insights to understand the nature of crisis (Mitroff, Alpaslan et al. 2004). Crises are by definition ill-structured problems. Different stakeholders will define them differently, depending on their values, interests, education, personal/community history and organization they work for. Several authors argued in favor of more refined distinctions between terms like disaster *versus* routine emergency (Heide 1989) or disaster *versus* catastrophe (Quarentelli 1997). From the many definitions of crisis/emergency/disasters that we find in the literature, we've adopted the following one: *Unwanted, unexpected, unprecedented situations almost unmanageable causing widespread uncertainty* (Rosenthal, Boin et al. 2001).

Regarding our research, we focus on the response to emergency situations characterized by disruptive events causing uncertainty of action and where time is of critical importance. Emergency Response (ER) in such scenarios may be considered a complex dynamic process in which constraints arise in real-time. The factors that contribute to complexity include: surprise, speed of development, spatial extension, number of involved stakeholders, uncertainty, perception gaps, lack of flexibility in decision-making, lack of available resources, lack of response options, inability to communicate and cascading events (domino effect) (Wybo and Latiers 2006). Under such conditions, the participants in ER scenarios will accumulate two main behaviors: Rule-based behavior and knowledge-based behavior (ESSAY 2000). Rule-based behavior relies upon existing contingency plans, most often developed with extensive simulation and training. Knowledge-based behavior relies upon contextual information, tacit knowledge and individual experience to address contingencies. In the knowledge-behavior mode, we assist to the emergence of work processes characterized by having no best structure or sequence, typically distributed, dynamically evolving, with unpredictable actors and roles; and also unpredictable contexts (Markus, Majchrzak et al. 2002).

The main organizational failures managing emergency situations, pointed out by in (McManus, Seville et al. 2007), may be rooted in a lack of collective awareness about the ongoing situation. Milis and Walle (2007) and Kanno and Futura (2006) it is also pointed out that communication, information management and the construction of Situation Awareness (SA) are major issues to ponder when addressing emergency situations. This paper is mainly focused on the construction of SA.

The following two sections are dedicated to overviews the existing to ER approaches and SA models, respectively. The section named Conceptual Model proposes our ER model. The Evaluation section describes an evaluation action conducted with IT service desk teams. The concluding section is dedicated to discuss our model and frame its usage in the context of High Reliability Organizations (HRO).

Details about the technological implementation are outside the scope of this paper. They may be consulted in (Sapateiro, Antunes et al. 2008). The model was implemented in a groupware system operating seamlessly in tablet PCs and PDAs. The implementation relies heavily on the assumption that technology will support peer-to-peer connectivity and real-time information sharing. The real-world constraints imposed by this assumption depend on the specific application domains and are also outside the scope of this paper. Projects like CHORIST and LIAISON have addressed these issues in the particularly challenging domain of firefighters teams support.

RELATED WORK

Traditionally, the emergency-handling models have been based on identifying stages, events, actions and the respective time frames. Overall, stages allow classifying the generic nature of the actions necessary to handle an emergency.

Events and actions are intertwined and often difficult to dissociate and classify. The traditional stages-view suggests there is some intrinsic order over time, but the reality is that it is the disorder within and between events and actions that most defines disastrous conditions (Kelly 1998). The stages-view is in the genesis of sequential models organizing disruptive situation in: pre-disruption, disruption and pos-disruption, the later being composed of stages involving Mitigation, Preparedness, Response and Recovery (Macreal, Badbury et al. 1997; Harrald and Stoddard 1998).

The stages-view has been subjected to criticism. First, different stages may occur at the same time. Second, some events are relevant to more than one stage. Third, the division is arbitrary and only useful to distinguish the major actions (Kelly 1998). Also, the pre- pos- division defines a separation between disruptive and normal operations that several authors have criticized. According to these authors, an efficient emergency handling strategy should encompass the continuous training and use of management tools/systems and procedures (Turoff, Chumer et al. 2004). The circular model overcomes these problems by concurrently integrating the disruptive and normal operations (Anderson 1985; TuscaloosaEMA 2003).

A number of emergency-handling models may be found in the literature emphasizing the different dimensions of emergency management. Some authors focus on specific hazards, like natural hazards (Wisner, Blaikie et al. 2003), at a more policy-making level. Others address specific application domains, e.g. firefighters (Jiang, Hong et al. 2004), at a more operational level. And many others emphasize specific management goals like preparation (e.g., cause driven models (Shaluf, Ahmadun et al. 2003)). The integrated and comprehensive approaches like (Sujanto, Ceglowski et al. 2008), although offering valuable guidelines, are still quite challenging to instantiate.

The existing models seem to provide few insights about the actual unfolding of a disaster. They lack a real-time view of the interdependencies between events and actions; and the situated adaptations of existing plans to the contingent factors that arise in emergency situations. From our standpoint, we need an emergency-handling model capable to maintain in real-time the multiple interdependencies between events, actions, actors, contexts, plans and any other factors involved in the process. Thus, in order to be useful, an emergency-handling model should move beyond the traditional phases towards a more dynamic and complex organization of all the elements that constitute the disaster.

MODEL FOUNDATIONS

Considering that our rationale concerns improving situation awareness, we conducted a review of the existing literature on situation awareness. Based on a synthesis of 15 definitions found in the literature, Dominguez (1994) cited in (Salmon, Staton et al. 2008) defines 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 directing and anticipating future events.

Since the late 1980s, a number of situation awareness models were proposed. The Ensdley's three-levels model is the one that has received most attention (Endsley 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 interaction with the world and that interaction modifies SA. This interaction is motivated by the disparity between the one's goals and the current perceived situation. This disparity comprises three stages: Orientational (development of an internal conceptual model), Executive (proceeding to a desired goal via decision-making and action execution) and Evaluative (assessing the feedback and influencing the Orientational and Executive stages).

Smith and Hancock (1995) proposed an ecological approach offering the most complete description of SA acquisition and maintenance. The model states that SA is neither resident on individuals nor in the world but rather on the interactions that are motivated by one's schemata, and that the outcome of that interaction will modify existing schemata, which in turn directs further exploration.

All the above models consider the individual construction of SA. The notion of team SA is more recent and currently lacks a universally accepted model (Salmon, Staton et al. 2008). Some literature on team cognition has been neglecting 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 a shared understanding of the same situation between team members (Endsley and Jones 2001). Shu and Futura (2005) posits that team SA is partially shared and partially distributed, as well as cooperative. 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.

Endsley and Robertson (2000) studied aviation maintenance teams and emphasize that good team SA is heavily dependent on understanding the meaning of the information that is passed. Besides this emphasis on communication, an additional aspect that revealed critical to team SA process is mutual monitoring, whereby team members monitor one another's activities and extract situational information without explicit verbal communications (Rognin cited in (Salmon, Staton et al. 2008)). This has emphasized the impact of shared mental models in team performance (Matieu, Heffner et al. 2000; Fiori, Salas et al. 2003).

A more recent approach to team SA, suggested by Stanton et al (2006), adopts an even more collaborative view. It suggests that, in complex collaborative systems, 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.

Ostensibly team SA is multi-dimensional, comprising individual SA, distributed SA, and shared SA. This multi-dimensional view posits many challenges to SA research.

Our emergency-response model is grounded on the previous works on team SA. It considers four critical factors for team SA development (Bolstad and Endsley 2000): 1) Shared SA - the degree each team member understands what information is needed by the other team members); 2) Shared SA devices - supporting communication and information sharing; 3) Shared SA mechanisms - supporting shared mental models; and 4) Shared SA processes - supporting effective team processes.

CONCEPTUAL MODEL

We conceptualize the emergency-management process as the construction and management of Situation Elements (SEs). A SE is a relevant (according to the application domain) element involved in the emergency-response process, like an actor, action, goal, resource, situation attribute.

We define Situation Dimensions (SDs) to agregate several SEs in a relevant set (again, relevance depends on the specific application domain). We may consider, for instance, SDs aggregating actors in specific teams, associating actions of a team, associating actions according a goal, etc. Figure 1 illustrates this conceptualization.

In order to semantically relate the SDs, we also define Situation Matrixes (SMs). A SM is a tuple (SDi, SDj, SVij) in which the first two constituents are two SDs and the last one, designated Semantics Vector (SVij), is a vector expressing the meaning of the relationship between the SDi and SDj.

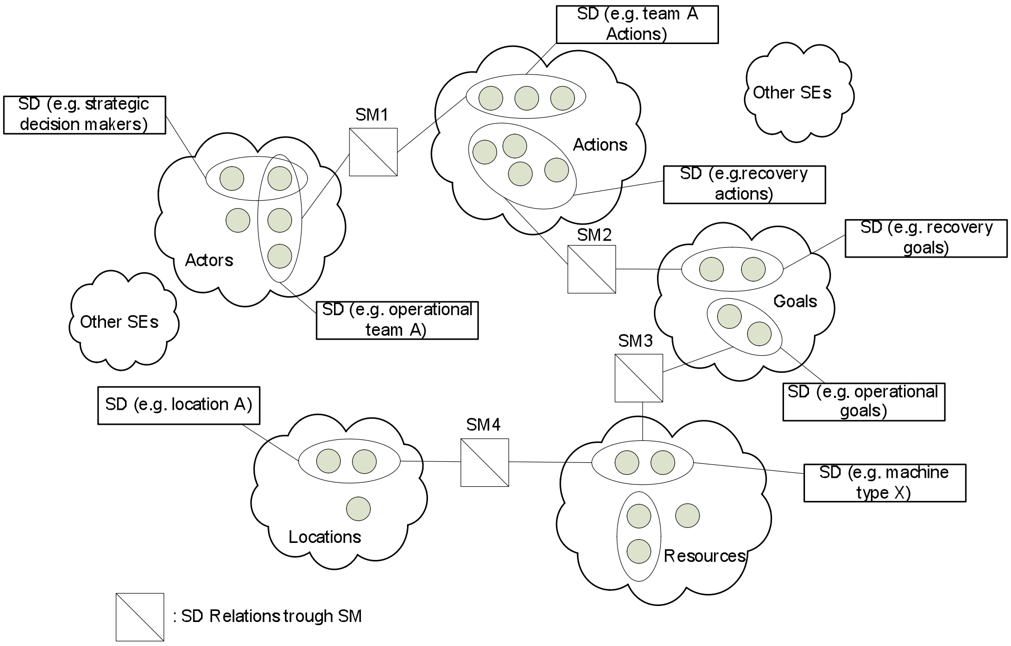

Figure 1. SE, SD and SM Conceptualization

Figure 1 presents some SMs correlating some SDs. Considering SM1, it sets the relationship between the SD constituted by the operational team A and the SD defining the actions assigned to that team. The semantic meaning associated to SM1 may define who is responsible for an action; or who will be affected by an action.

If we consider SM4, in Figure 1, it defines the relationship between a specific resource and an incident that occurred in location A. Other possible semantic linkages between these SDs may consider where resources are located and/or where they are needed.

As already stated, the definition of relevant SDs, as well as their relationships, are materialized trough the SM. The concrete meanings should be elicited from the particular application domain and adapted to the involved actors. Factors like team structure, training and procedures, as well as the specific types of disruptive events that may be addressed, will strongly dictate the choice of relevant SDs and SMs.

Regarding the proposed model dynamics', we shall consider that handling emergency situations encompasses a number of information and communication flows (Landgren 2006; Gonzalez 2008). The SM artifact performs a key role in mediating these flows, supporting information sharing and persistence, as well as visualization. Figure 2 depicts the flows involved in an emergency response scenario.

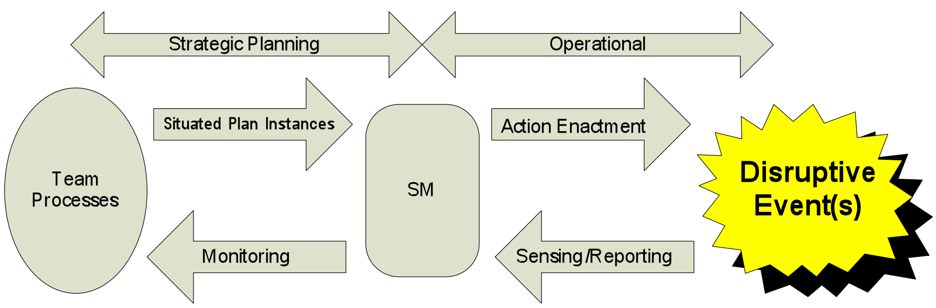

Figure 2. Information flows

Taking a systems approach, the involved participants may be regarded both as sensors and as actuators in the emergency-management process. While acting as sensors, the involved participants establish closed feedback loops by updating the SEs' relationships trough SMs. Monitoring the SEs' dynamics affords accommodating to events, contingencies and context changes. This constructivist perspective promotes the adaptation between previously defined / trained plans (which deploy the initial set of SEs, SDs and SMs) and the current emergency situation, by allowing the participants to progressively and collectively contribute to characterize the situation and handling strategy. SMs will thus accomplish two critical goals: support the externalization of often-embedded knowledge, and provide a support for monitoring the patterns that may trigger contributions from the involved participants.

The discussion about who has permission to contribute to the SMs (including real-time handling of SEs, SDs and SMs) is outside the scope of this paper and should be evaluated in the specific application domain. Though some compromises have to be considered between "order" and flexibility/resilience and "authority" and collaboration. Figure 3 illustrates the collaborative use of SMs.

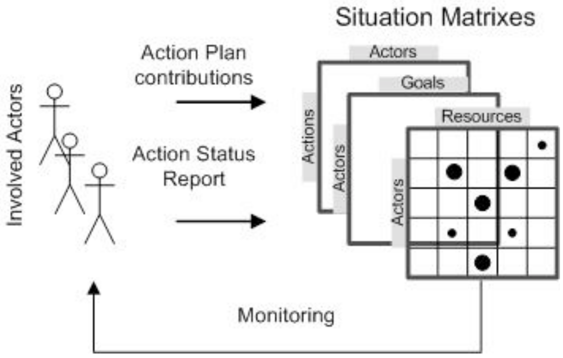

Figure 3. SM collaborative usage

The visualization scheme necessary to convey the relationships done in the SM cells (illustrated in Figure 3) is also an important part of the model implementation. Different colors, symbols and/or sizes may be used to express the semantic meanings behind relationships. Considering that not all involved participants have the same SA needs, the correlations may be filtered according to specific roles, actors, or events.

The SMs constitute real-time control panels of relevant SDs, assisting the alignment of SEs toward emergency mitigation, suppressing the pathway for incident progression as conceptualized in the Swiss Cheese model (Reason 1997).

EVALUATION

Aiming to evaluate the proposed model, we conducted experiments with two IT Service Desk (IT SD) teams operating in two different organizations. These teams often face situations classified as emergencies. For instance, if a network link or a server is down, it may compromise business continuity. The first team was constituted by three senior and two junior members. The second team had the chief, one senior and one junior member.

Several alternatives to evaluate the proposed model were considered. Although the field methods allow capturing more realistic problems and requirements, they could be difficult to settle for several reasons: time investment, scenario setting, difficulties analyzing ongoing emergency situations, etc. We thus adopted a discount inspection technique combined with the scenario-based approach. As pointed out in (Steves, Morse et al. 2001), it is possible to contextualize inspection techniques through the use of work scenarios (Carroll 2000) jointly constructed with domain experts. Such an approach may lead to finding many of the same problems that are found in field studies.

We started with semi-structured interviews with each IT SD team member, aiming to establish some common ground about emergency management and the respective application domain. Table 1 summarizes the topics discussed in the interviews.

The interviews revealed the most serious emergencies were related with server failures (in which the more frequent problem is the disk failure) and connectivity losses in some network segments (that may be due to switches' firmware problems) compromising a wide variety of services. It was also reported that more untypical problems may occur and lead to emergency situations, "[…] like a flood in the basement where some of the equipment is situated […]"

Which situations may be described as emergencies
Current preventive practices
Current diagnosis practices
Current registration practices
Current recovery formal procedures
Current recovery informal procedures
Current communication schemas
Existing performance metrics
Priority near future improvements (address current identified vulnerabilities)

Table 1. Interview's Discussed Topics

The existing preventive practices rely heavily in monitoring the active network elements trough a control panel fed by SNMP messages, where alerts are displayed and emailed to the technicians. Also, several equipments are under SLA agreements with suppliers and a spare stock exists. Actual diagnosis and recovery practices rely heavily on the field experience of each team member and the fact that they all know the intervention domains of each one (e.g., some team members address Linux and others Windows problems).

In order to present our conceptual model and discuss its application in the IT SD domain, we done two workshops with the team members and discussed the model support in a scenario previously defined with the team leader. The workshops were divided in 3 phases: 1) present the model; 2) discuss it's usage in the IT SD domain; and 3) discuss the details of the technological implementation.

We supported the discussion using paper prototypes representing the SM artifact (Figure 4a). This allowed us to focus on the model and avoid the typical usability disturbances often experienced with preliminary evaluations recurring to technological implementations.

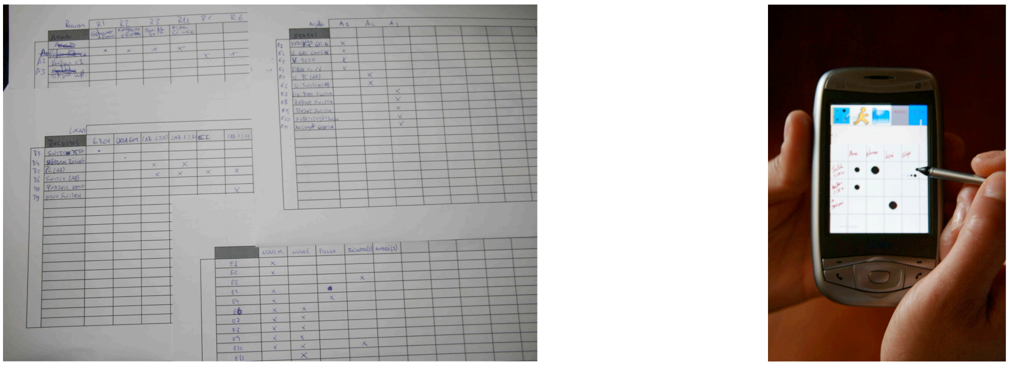

Figure 4. a. SM paper prototype b. PDA prototype

From the discussed scenario and paper prototypes, the following SDs were proposed: Equipments, Actors, Locations, Actions and Activities. These SDs should be correlated in the following SMs:

1. Actions-Steps, detailing operational activities (e.g., check router X, reboot switch Y);
2. Actors-Steps, defining responsibilities;
3. Equipment-Actors, expressing the persons responsible for the equipment (e.g., who is empowered to activate a supplier warranty, who is habilitated to inspect a Linux server or a specific service);
4. Equipments-Locations, allowing team members (mostly junior) to know the equipment locations (e.g., main gateway of building C6 is located in room 6.3.0.1).

The participants additionally referred that the persistent data would serve for future reference (addressing future incidents or conducting post-mortem analysis' to improve response strategies).

Since the proposed model heavily relies on real-time information sharing, its dependence on the technological implementation is obvious. A preliminary PDA prototype implementation was therefore presented to the participants (Figure 4b). Implementation details may be consulted in (Sapateiro, Antunes et al. 2008). The main comments regarding the implementation concerned the SMs navigability, the visualization schemas; and the development of alternative strategies to user report information. One of the discussed ideas was the adoption of a pull strategy that would be triggered in some cases by the system and in the other cases by the team members, where users would be prompted to confirm the status of a specific SE. All the comments indicate a preference for simple, quick and low-overhead usage.

DISCUSSION AND FINAL REMARKS

In this paper we propose an emergency response model grounded on the construction of shared SA. Considering the existing research on SA, the proposed model focus on organizing SEs trough SDs that may be semantically interrelated trough the proposed SMs, in order to make sense of the ongoing situation. Several works have identified relevant dimensions and respective relationships regarding emergency situations. In (Wybo and Latiers 2006) is emphasize the socio-organizational (roles and interactions) and spatial (locations) dimensions. Also, Jonas Landgren, in his PhD thesis (Landgren 2007), based on 700 hours of ethnographic studies with fire-fighters, proposed the Actors-Actions and Location-Situated Attributes dimensions. Other authors emphasized the need to relate capacity *vs* vulnerability (Kieft and Nur 2001), actors *vs* recovery actions (Yasemin and Davis 1993), risk sources *vs* risk elements (Salter 1997), Harzard assessement *vs* risk and Risk *vs* actions (Nasghar, Alahakoon et al. 2005), and situation inputs/resources *vs* impacts (Kelly 1998).

Our proposed approach may be seen as a meta-model that may be instantiated in specific application domain models according to the SEs, SDs and SMs considered relevant to that domain. Furthermore, the propose approach allows specifying these elements in runtime.

The model evaluation focused on IT service desk teams as an application domain in which systems failures may compromise business continuity. The outcomes yield the model was perceived as relevant to the domain experts. Other application domains are also under study, e.g., airport maintenance teams, in which the major difficulties reported concern with perceiving in real-time the status of different SEs as the emergency unfolds. A collective SA approach seems to be strongly appreciated.

The proposed collaborative approach has its roots on High Reliability Organizations (HROs), which posis that under exceptional conditions, decision making process become more collegial, deferent to expertise and decentralized to the levels where actions must be taken (Hayes 2006). Deference to expertise is also seen as a key quality exhibited by HROs (Weick, Sutcliffe et al. 1999), which is well aligned with our approach. Depending on the kinds of organizations and emergencies, different response structures may exist or emerge. The traditional command and control approach has been heavily criticized for not taking into account the emergent properties of critical situations, favoring a concentration of decision-making and putting too much emphasis on hierarchical communications and pre-planning (Drabek and McEntire 2003). Instead, disaster sociologists emphasize that emergency response operations should be organized with a decentralized structure and accommodating the cooperation between involved actors Furthermore, they also advocate that an emergent behavior is beneficial to the extent that new organizational structures (virtual ones), as part of the response work, will bridge the existing organizational gaps.

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