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Evaluating the Use of Mobile Devices in Critical Incidents Response: A Microworld Approach

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Abstract—**In this work we approach the study of team situation awareness based upon a holistic perspective that integrates the shared and distributed nature of the construct. We studied team situation awareness in the context of critical incidents response management, as it constitutes a valuable asset and yet is continuously challenged by the very nature of the context. We applied a microworld approach as a compromise between controlled laboratory experiments and field studies. Relying on this approach, we studied the impact of mobile applications in the teams' performance and situation awareness, using a helpdesk as an application domain. The obtained results do not indicate a fundamental breakthrough regarding the usage of mobile applications in such contexts. Nevertheless, they provide valuable insights about the team dynamics, situation awareness and communication patterns.**

Keywords: situation awareness; mobile devices; microworlds; team work; incidents management.

I. Introduction

A number of critical incidents demand organizational responses outside pre-established procedures. Examples of such incidents range from the more typical loss of a key organizational resource to the more extreme natural disaster. In the scope of this work a critical incident is defined as: an unwanted, unexpected and to some extent unprecedented chain of events, causing an uncertain course of action, and depending on time to overcome the disruptive effects [1].

Most often these incidents are addressed at the team level because teams afford dynamic responses, bring together various types of information sources, and ease complexity control. We find in many organizations various types of teams specifically set up to deal with critical incidents, such as helpdesk teams, special project teams, and security teams, among many others.

These types of teams are characterized by being strongly reliant on knowledge and action, the reason why Team Situation Awareness (TSA) may very well be their most critical capacity. For instance, TSA has been considered critical to coordinate emergency actions and to achieve high performance levels under emergency situations [2, 3].

From the literature review reported in [4], we have adopted the following definition of Situation Awareness (SA): 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. This definition offers a holistic perspective integrating the product dimension (the attained SA) and the process (the situation assessment activities) dimension.

In this research we seek to understand the role mobile devices can play supporting TSA in the context of Critical Incidents Response Management (CIRM). We are particularly interested in CIRM contexts requiring teams to spread across different locations, emphasizing the possibilities brought by the now ubiquitous mobile technology.

However, evaluating TSA in these scenarios is very challenging. Among numerous reasons, we highlight:

- Incidents are unexpected and thus difficult to plan experimentally;
- Addressing an incident is context dependent, which constrains the generalization of the incident studies;
- Several factors such as frequency of occurrence and risk make it difficult to study CIRM;
- Teams do not have many incentives to participate in the controlled studies required by TSA; and
- Teams use domain-specific jargon, which is often a barrier to establish a common ground for the study.

To address these challenges, we adopted a microworld approach. A microworld is a research platform that serves to collect very detailed data about the teams' information-management activities in complex and dynamic scenarios [5]. In our case, the microworld serves to collect data about communication, coordination and the use of mobile technology.

We note that relying on mobile technology to construct TSA in CIRM scenarios may be questioned. Several research works have already addressed this issue, proposing real time on site deployment of connectivity centres, for more extreme circumstances [6]. Despite such issue is beyond the scope of this work it complementarily emphasize the difficulties faced by research regarding the evaluation of the use and effective impact of mobile technology in CIRM.

We selected helpdesk teams as an operational domain. Helpdesk teams often face CIRM situations, when they have to deal with disruptive events such as server failures and connectivity problems, which challenge business continuity and quality of service [7].

In helpdesk work, pre-established procedures may reveal useless (due to the specificity of the situation) or even be non-existent (which is often the case in one-of-a-kind problems). While addressing CIRM situations, helpdesk teams must rely

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on the tacit knowledge of the participating team members and often, due to the time pressure, tend to develop temporary workarounds to stabilize the problems. This lack of formality and reliance on contingency also challenges TSA.

In the next section we review the literature and present the theoretical basis of our work. In section III we present the developed microworld environment. Section IV describes the design and results obtained from an experiment using the microworld. We conclude the paper discussing the experimental results and proposing future research directions.

II. Work Foundations

A. Perspectives on the Nature of Incidents

The existing perspectives on critical incidents fall into three main categories: sequential, epidemiological, and systemic [8]. In the sequential view, incidents are the result of a sequence of clearly distinguishable events that occur in a specific order (see, for instance, the Domino Model [9]). The focus here is on a causal perspective, which often neglects the contextual/situated factors.

The epidemiological view offers an alternative to the oversimplified sequential models by considering incidents as a combination of organizational factors. A classic example is the Swiss-Cheese Model [10]. Although causality is still based on a single linear propagation of effects, the epidemiological models incorporate the contextual/situated factors explaining the incident trajectory[8].

The systemic view states that incidents cannot simply be explained by cause-effect relationships, but instead they are the outcome of complex interactions and coincidences between multiple components that influence each other in often unpredicted ways [11, 12]. The systemic view thus considers incidents as a combination of external and internal factors, both contributing to explain the incident trajectories. The systemic view inspired our approach to the study of TSA.

B. Team Situation Awareness

Since the late 1980s, a number of SA models mainly from the aviation and military domains have been proposed. They can be classified as either individual- or team-oriented. At the individual level, the Ensdley's three-levels model is the one that has received most attention [13]. It views SA as: a) monitoring environmental elements; b) diagnosing their meaning; and c) projecting their future consequences.

Other researchers have proposed more dynamic views. Bedny and Meister [14] rooted their research on activity theory, modelling SA as a continuous loop on which SA directs the interaction with the world that in turn modifies SA. Smith and Hancock [15] proposed an ecological view where SA is neither resident in the individuals nor in the world, but rather on their interactions.

The development of team-oriented views is more recent and currently lacks a universally accepted model [4]. Some researchers emphasize that teams do not only overlap individual SA but they also construct TSA [16]. This approach considers the team as the fundamental unit of analysis [17, 18].

Thus, TSA combines individual SA (necessary to conduct individual tasks) with a shared understanding of the situation constructed by the team [19]. Shu and Futura [16] posit that TSA is partially shared and partially distributed.

Some recent approaches emphasize the role of collaboration in TSA [20] and posit that in complex incidents individuals rarely perform totally independent activities. Instead, they are coupled and tend to coordinate their actions. Our research is in line with the view that collaboration and coordination should be analysed to understand TSA.

C. Measuring Team Situation Awareness

The measurement of TSA is quite challenging, particularly in ill-defined processes such as those experienced by CIRM. Though several measurement techniques can be found in the literature. They can be organized in two approaches, depending on the adopted SA view: product-oriented or process-oriented.

Regarding the product-oriented view, we observe that most measurement techniques focus on assessing the operator's memory contents, that is, the product of SA. The process-oriented approach focuses on finding why the operator exhibited some measured level of SA, and on determining the implications of that measurement. Table I presents a taxonomy of TSA measurement techniques based on [4, 21].

TABLE I
TSA Measurement Techniques

Method	Approach	Examples
Indirect	Task/team activities based	Think aloud Communications analysis
	Psycho/physiological based	Eye tracking
	Behavioural	Observable behaviour Scenario manipulation
	Performance based	Embedded performance indicators
Direct	Subjective	Self rating SART[1] SARS[2]
	Objective	Questionnaires SAGAT[3] SPAM[4]

1) Situation Awareness Rating Technique; 2) Situation Awareness Rating Scales; 3) Situation Awareness Global Assessment Technique; 4) Situation Present Assessment Method.

Since TSA is operationalized differently across research disciplines and application domains, it is somehow difficult to establish a universal criterion for comparing the measurement techniques. All techniques presented in Table I have strengths and weaknesses.

Some are more intrusive (disrupting normal activity and interfering with the task performance), while others are biased by a number of factors such as the type of training the teams have. The individual skills and personal characteristics (for instance, pro-activity) may also influence the TSA measurements. Further discussion about these methods is outside the scope of this work and can be found in [4, 21].

Related with all these factors, one may also consider the impact of the task design. Of course the task should be as close as possible to the natural setting. But as already emphasized in the introduction, CIRM contexts are difficult to study in natural settings. Our research was based on the microworld approach introduced in the next section.

D. Microworld Approach

Microworlds are dynamic, real-time and task-oriented environments used to study human behaviour in simulated scenarios, retaining real world complexity while omitting other aspects deemed superfluous for the purposes of the research [5]. Microworlds are carefully designed to support experimental manipulation and control of the task environment without removing its naturalistic characteristics, an approach that can engage people to the point that their behaviour becomes natural [22].

A key characteristic of microworlds is the explicit handling of dynamic complexity, a long-time concern of decision-making studies, as evidenced, for instance, by the beer distribution game, which has been played for almost half a century to show executives and managers how dysfunctional behaviour can arise from the interactions among players [23].

The potential to create unpredictable and emergent behaviours has also been investigated, uncovering many contradictions in organizational learning [24] and decision making [25]. Interestingly, many sources of dynamic complexity explored in microworlds are related with the systemic approach to CIRM, namely:

- The tight coupling between the operators' actions and the environment means that what one does changes the situation and the subsequent actions. The operators and the environment continuously influence each other and are governed by feedback loops [26], meaning that a clear cause-effect path may be difficult, if not impossible, to discern;
- The trade-offs in decision-making, especially considering the timing constraints and the amount of information available, can be difficult to handle. An example is the duality between a global leader who understands the whole situation but lacks the information necessary to act locally, versus a local leader who can act locally but has less information about the overall situation [27]. Again, it may be hard to determine clear cause-effect paths between the decisions and their consequences; and
- The effects of an action can be disproportional to cause because of the number of variables involved and their interactions, which often are not well known. One characteristic of microworlds is that they purposefully hide some aspects of the system, meaning that the operators have to continuously test their hypothesis to understand what is going on in the environment [5], which actually reflects the typical CIRM scenarios.

Microworlds have been widely adopted in human-factors research and cognitive systems engineering, considering scenarios such as naval warfare[28], industrial process control [29], air traffic control [30], naturalistic decision-making [27], fire fighting [31], and other complex problem solving scenarios [32, 33].

Another important characteristic of microworlds is that they allow collecting large amounts of data, which are necessary for hypothesis testing. Moreover, microworlds may provide very cost-effective platforms for concept validation early in the development cycle [34, 35].

III. THE MICROWORLD ENVIRONMENT

We developed a microworld environment to study TSA in CIRM, seeking to obtain experimental data closer to the decision-making context experienced by helpdesk teams in real-world scenarios. Four main software modules support the microworld: 1) VoIP communication; 2) task environment; 3) mobile application emulator; and 4) TSA questionnaires.

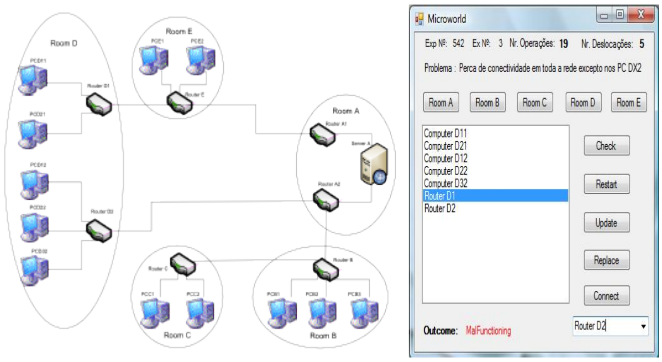
A. VoIP Communication Module

Considering our previous studies conducted with helpdesk teams [36], the VoIP module allows two team members to communicate with each other, emulating the typical phone conversations that take place in helpdesk teams. This type of communication addresses two main purposes: a) communicate the outcome of a task performed by a team member; and b) ask a team member to accomplish a task.

B. Task Environment Module

The task environment module allows loading different task configurations necessary for the experiments. In the case described in this paper, the task involved helpdesk teams resolving network failures. Therefore the task environment was set up to emulate a building having various rooms with computers, servers and routers, where the critical incidents could originate in any one of these devices.

Fig. 1a presents one of the network architectures that was used in the experiments, while Fig. 1b depicts the respective screenshot of the task environment module.



a. b.

Fig. 1. Virtual Network Module

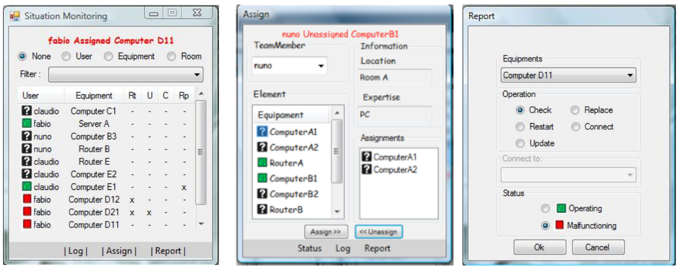
Using the task environment module, the participants in the experiment could move throughout several rooms to check the existing network devices and to apply some typical actions such as restarting the device or updating the device configuration. The complete list of operations simulated by this module is presented in Table II.

TABLE II
TASK ENVIRONMENT OPERATIONS

Operation	Description
Move	List the devices available in the selected room
Check	Provide the current state of the device (working or malfunctioning)
Restart	Simulate a restart operation on the selected device, yielding the resulting state
Update	Simulate an update operation on the selected device, yielding the resulting state
Replace	Simulate a replace operation on the selected device, yielding the resulting state
Reconnect	Provides the possibility of reconnecting the device to other network segments (e.g. connect a PC to other router, selected from a predefined set of alternatives)

C. *Mobile Application Emulator Module*

The mobile application emulator implements the following features: a) share information about the task situation, in particular the devices' status, as shown in Fig.2a; b) assign activities to team members, as shown in Fig.2b; and c) update the shared information by reporting the outcome of a device operation, which is illustrated in Fig.2c.



a. Monitoring screen b. Assignment screen c. Report screen

Fig.2. Mobile application emulator

D. *Team Situation Awareness Questionnaires Module*

The TSA questionnaires module periodically freezes the task to prompt the team members with a predefined set of questions regarding TSA. This feature is grounded on a common practice in cognitive and work load studies [37] and is the base of SA measurement techniques such as SAGAT [21]. The questionnaires are delivered after a pre-established number of operations, which depends on the specific exercise. During the freeze, the operation of the other modules is suspended. A full description of the microworld architecture and modules is reported elsewhere [38].

IV. EXPERIMENT

The experiment engaged 33 students from the final year of an undergraduate course in informatics. To participate in the experiment, it was mandatory that the students had completed a course on computing networks. A consent form had to be signed stating their commitment to the experiment and authorizing data collection. Additionally, prize money and extra course credits were offered to the best performers to encourage deeper task engagement.

The teams were composed by three elements playing the following roles:

- Team Member 1 (TM1) has high-level credentials, allowing operations on any network device, namely servers, routers and computers;
- Team Member 2 (TM2) has middle-level credentials, allowing operations on routers and computers, but not on servers; and
- Team Member 3 (TM3) can only operate computers.

This team composition was suggested by our previous studies with helpdesk teams [36].

Before the experiment, the teams received a manual describing the experiment goals, roles, and tools. Briefing sessions were also organized in the beginning of each session to clarify any doubts regarding the experiment.

A. *Experimental Design*

Several exercises were defined, each one requiring diagnosing a connectivity problem in a different network infrastructure. Each team solved four exercises.

The odd teams started with the experimental condition, which provided voice communication support but no mobile application, referred as "W/O" condition. They solved two exercises, the first for training purposes, to get familiar with the setting, and the second for effective experimental data collection. After the first two exercises, the odd teams were subject to the second experimental condition, which besides voice communication also provided the mobile application, referred as "W/" condition. In the second experimental condition the teams performed two more exercises, the first for training purposes and the second for data collection.

Even teams performed in the reverse order. The first pair of exercises were conducted based on the "W/" condition and the second pair of exercises were performed in the "W/O" condition.

At the end of the second and fourth exercises, the teams had to complete a debriefing form regarding the team operations, understanding of the situation and perceived workload, evaluated through a NASA TLX questionnaire [39]. After completing these questionnaires, the teams were also requested to participate in a short debriefing session to provide a consensual opinion about their course of action. The SA questions used in the freeze probes, raised during the data collection exercises, are presented in Table III.

TABLE III
SA QUESTIONS USED ON THE FREEZE PROBES

ID	Question
[Q1]	What are the states of the devices linked to the last operated device?
[Q2]	In what room are the team members currently located?
[Q3]	Which devices are currently constraining the network connectivity?

Three observers standing close to each participant during the experiment coded the voice messages. The following types of codes were defined: a) ask information; 2) provide information; 3) assign activity; and 4) receive an assignment.

Several trials were conducted to fine-tune the experimental parameters, in particular the duration of the exercises and the number of device operations that would trigger the freeze probes. These trials were also used to adjust some of the application functionality.

Based on the typical metrics reported by the related literature, we established a set of experimental measures comprehending performance indicators [P1-P3] and SA indicators encompassing the holistic perspective adopted. Therefore, these indicators comprehend the assessment of individual [IA] (knowledge that team members individually have regarding the situation) , shared [ShA] (knowledge overlap between team members), and distributed SA [DA1-DA2] (aggregated knowledge that the team possess as a unit) (see Table IV).

TABLEIV
METRICS DEFINITION

ID	Metric	Description
[P1]	Completion Time	Time took by the team to complete the exercise
[P2]	Efficiency	$\frac{\text{ideal number of operations to solve the exercise}}{\text{number of conducted operations in the virtual network}}$
[P3]	Efficacy	$\frac{\text{number of final working equipments}}{\text{achievable number of working equipments}}$
[IA]	Individual Awareness	$\frac{\text{number of correct items in freeze probes answers}}{\text{number of questioned itens in freeze probes}}$
[ShA]	Shared Awareness	Overlap of individual correct answers in the freeze probe SA questions
[DA1]	Distributed Awareness	Team average of individual scores in the freeze probe questionnaires
[DA2]	Distributed Awareness	Team average of individual scores debriefing forms

B. Results

Concerning performance, the task completion time [P1] of W/teams was significantly longer than the W/O teams. We used the non-parametric Wilcoxon signed-rank test for paired comparisons to evaluate the statistical significance of the results (see Table V).

TABLEV
COMPLETION TIME [P1]

Average P1 (considering both conditions)	9.39
Average P1 (w/ condition)	10.55
Average P1 (w/o condition)	8.23
Wilcoxon signed-rank test p-value	0.016

The analysis of [P2] and [P3] did not reveal any statistically significant differences between the experimental conditions. Therefore the mobile application had no significant impact on performance.

In order to give a better understanding of the following results, concerning SA, we point out that the freeze probes were triggered three times in the course of the exercises. Regarding individual awareness [IA], the collected data did not reveal any significant differences between the three freeze probes.

The overlap of individual awareness [ShA] was analysed by considering pairs of correct answers, that is, two team members giving the same correct answer, and triplets of correct answers, when all team members responded correctly. This analysis yields a score calculated from the ratio between items correctly answered (by pair/triplets) over the number of items in the question.

Despite the lack of statistical significance in the obtained [ShA] scores, we note that in the W/ condition the teams exhibited better results, both in paired and tripled correct answers, regarding questions [Q2] and [Q3] when reaching the final freeze probe, as shown on Table VI.

TABLE VI
SHARED AWARENESS [SHA] SCORES

	Q2		Q3	
Condition	**W/**	**W/O**	**W/**	**W/O**
Pairs	0.53	0.31	0.86	0.55
Triplets	0.36	0.17	0.45	0.09

In other words, there are some preliminary indications that the use of the mobile application may improve shared SA regarding the team members' location [Q2] and the problem identification [Q3].

The analysis of distributed awareness [DA1]was based on the average scores of individual answers in each freeze probe to questions[Q1, Q2, Q3].Despite the results do not reveal significant differences, a more detailed analysis provides interesting insights about the evolution of SA over time.

The answers to [Q1], regarding the status of the most recently operated devices, show a slight improvement from the first to the second freeze probe, and then reached a plateau in the third iteration, as shown in Fig. 3a.

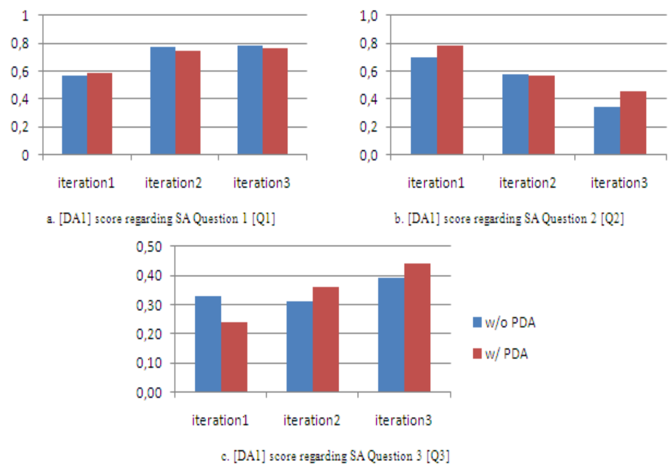


Fig. 3. Distributed awareness [DA1]

[Q2] reveals that, as the exercise unfolds, the teams loose awareness of where the others are located. As shown in Fig. 3b, W/ obtained better scores than W/O.

[Q3], which concerns the identification of the malfunctioning devices, reveals that teams improved their aggregated SA throughout the freeze probes, with a slightly advantage obtained by the W/ condition, as shown in Fig. 3c.

We conclude this section with an analysis of distributed awareness [DA2], which yield a statistically significant difference (Wilcoxon signed-rank p-value=0.0117), indicating that W/ teams had a better perception about the operations performed in the network. A detailed analysis of the responses reveals that the team members who benefited the most from the W/ condition were those playing the TM2 and TM3 roles. In other words, the roles with lower credentials to access the network equipment, typically associated with less experienced members, benefited the most from the shared application.

C. Discussion

The collected data indicates that the W/ condition does not constitute a fundamental breakthrough in TSA and performance. But a fine-grained analysis of the collected data reveals some interesting differences. We present two additional dimensions of analysis where such differences are apparent. One concerns voice communication and the other shared application usage.

In the W/ condition, the teams exchanged fewer voice messages (Wilcoxon signed-rank p-value=0.05, see Table VII). Furthermore, the nature of the communications was different in both conditions: W/teams asked less information and also provided less information than the W/O teams, as shown in Table VII.

TABLEVII
VOIP COMMUNICATIONS CODING

	Ask for information	Provide information	Receive an assignment	Assign a task
W/O	104	154	30	45
W/	52	83	20	40
Wilcoxon p-value	0.011	0.019	0.21	0.33

These results are consistent with the fine-grained analysis of the actions performed by the team on the shared application, which indicates that information monitoring and reporting were the most frequent actions (Fig. 4).

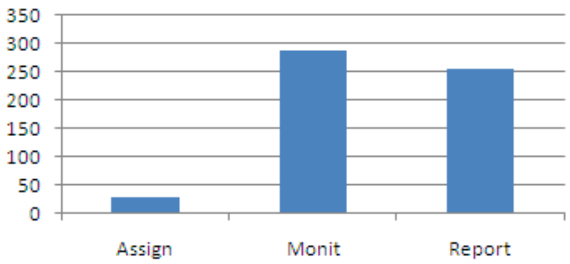


Fig. 4. Number of times the shared application's screen was visited by the team members

Our final remark concerns the perceived workload elicited from the TLX questionnaires filled out in the debriefing sessions. That analysis did not yield any significant differences regarding the use of the mobile application.

V. CONCLUDING REMARKS

The main theoretical endeavour of this research relies on the conceptualization of TSA as the combination of individual, shared and distributed dimensions. Our research focus was on studying TSA in the challenging CIRM context, where TSA plays a critical role in incident response.

We developed a microworld for studying TSA, seeking to obtain experimental data closer to the teams' decision-making context experienced in real-world scenarios. Our microworld studies involved a scenario where helpdesk teams had to recover the network infrastructure after a critical incident.

The microworld proved to be a rich data collection medium, providing solid grounds for consistent data collection. The results from the conducted experiments indicate that empowering teams with TSA support, based on mobile applications, does not necessarily increase performance. Instead, the teams seem to rebalance their information needs based on what communication channels they have available.

While still using voice communication, the studied teams seemed to embrace the mobile application as a convenient, albeit redundant, communication channel that reduced their voice communication needs.

A complementary point to consider is a side effect from using the mobile application: it allows documenting the course of action, especially regarding what has been done to diagnose and recover from the incident. This information is fundamental to support organizational learning and memory. This feature goes beyond the capacity of voice communication and constitutes an additional driver for further research on mobile applications and their applicability in CIRM scenarios.

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