Effects of Real-time Imaging on Decision-Making in a Simulated Incident Command Task

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ABSTRACT

Eight Incident Commanders (ICs) took part in a simulation exercise to determine the impact of real-time imaging feedback on situation assessment and decision-making in an uncertain and high-tempo environment. The imaging feedback simulated the video feed from an unmanned aerial vehicle (UAV) that allows incident command centers to monitor developments at the crisis site. Nearly all of the ICs failed to detect important changes in the situation that were not captured in the imaging but that were available via other, more traditional data sources. It appears that the ICs placed an inappropriately high level of trust in the imaging data, resulting in a narrowing of their data search activities and limited cross-checking between the data sources being used. This research helps anticipate and guard against undesirable effects of introducing similar technologies on training and operational procedures in a variety of domains.

Keywords: *command and control; crisis management; decision-making; feedback; fixation; incident command; presence; sense making; UAVs (unmanned aerial vehicles)*

INTRODUCTION

Managing an emergency response presents the decision-maker with many of the challenges observed in any complex, naturalistic setting, such as: time stress, high costs for failure, and solving ill-structured problems with limited reliable information (Klein et al, 1986). Efforts to support decision-making in such environments often revolve around introducing technologies that increase the amount of, and timeliness of, available data. In the case of incident command, several remote-sensing technologies that provide real-time imaging to decision-makers have begun to be utilized during emergency response operations. It is expected that this new feedback channel will aid in situation assessment and also allow planners to consider challenges faced by local operators (e.g., restricted access, potential dangers) as they develop response strategies.

However, previous research has shown that altering the nature and/or the timing of the information available to a practitioner invariably alters the nature of the cognitive work needed to process it, often resulting in new challenges and new pathways to failure (Billings, 1997; Norman, 1990; Sarter and Woods, 1992, 1995; Smith et al., 1997). Independent of whether the new technology provides the expected benefits, or simply exchanges one set of challenges for another, its introduction produces a point of change that offers a unique opportunity for analyzing how the cognitive work in that domain is conducted (Cook and Woods, 1996; Patterson et al., 2002). The current research seeks to take advantage of one such opportunity—the introduction of real-time image-based feedback into emergency management. The availability of unmanned aerial vehicles (UAV) allows incident command centers to monitor developments at the crisis site remotely. This new data channel provides real time video that allows incident commanders to monitor developments at the crisis site. The goal of the study is to assess how this new data channel changes data gathering, integration, and sense making of emergency management decision-makers. Command centers find access to real time images from the scene of interest to be very compelling, but anecdotal reports and observations from exercises and deployments suggest the new image data channel may be too compelling and lead command decision makers to over-rely on information from this one data channel. This study observes eight actual incident commanders manage a simulated crisis (petro-chemical plant fire) with a real-time feed providing images of the crisis site. The crisis management exercise evolved in ways designed to challenge incident command decision making, in particular, to reveal if the incident commanders over-relied on information coming in through the image data stream and under-utilized information available from other data channels.

Challenges in Incident Command

Emergency operations management is a classic case of has been termed "multi-threaded work" (Woods and Hollnagel, 2006), in which the practitioner must assess the situation by gathering and integrating multiple data sources, detect anomalies in the evolution of events, and exercise authority over a distributed, multi-level organization. Incident Commanders (ICs) generally prefer to gather information via direct observation which provides them detail-rich data without delay and allows them to apply their expertise to draw meaning from the raw data given the uncertainties of emergency situations.

However, in managing crisis events, ICs often have limited access to first-hand information. The physical size of many incidents often limits the IC's ability to directly observe the entire situation. Instead, the data they receive is often mediated, or processed, through other actors and subject to delays. Both of these conditions can limit their ability to assess the situation, re-plan and manage the overall response operation (Brehmer and Allard, 1991; Johansson et al, 2002; Woods et al, 1994). Feedback delays present a challenge to the decision-maker whose expertise "is tuned to the future" (Woods, 2002). The goal of anticipating events, rather than reacting to them, often drives the IC's desire for more, more direct, and more immediate feedback (Danielsson and Ohisson, 1999).

The majority of the information used by the IC consists of verbal or text-based messages from remote team members. However, verbal communications between non co-located team members can be time-consuming, requiring turn taking between the participants in order to establish and maintain "common-ground" (Clark and Brennan, 1991). While vital for reducing ambiguity, this context building requires continuous effort in a highly dynamic, multi-task environment. Similarly, receiving text-based data from multiple sources can require significant cognitive work to integrate into a cohesive framework needed for making sense of the developing situation and the effect of countermeasures.

Supporting Data Analysis and Sensemaking

The above challenges emphasize how the information requirements of the IC often outstrip the abilities of the available data channels to provide the desired feedback in the course of managing an incident response. The design goal then is to enhance the ability of the IC and their staff to quickly obtain relevant information needed to understand the nature and scope of the crisis, to assess the effect of remedial activities, and to project how the incident may evolve.

One proposed solution to this challenge is to provide ICs with real-time imaging of the event via unmanned aerial vehicles (UAVs). In addition to providing detail-rich data, the overhead perspective afforded by a UAV is expected to enable ICs to quickly develop a global perspective of the situation and also to consider challenges faced by local operators (e.g., restricted access, potential dangers) when they are developing their response strategy.

A key advantage of image-based data over the verbal and text-based information is that it transforms the cognitively demanding task of creating and updating a mental model of spatial relationships into a less demanding perceptual task (Norman, 1993). The image data channel allows ICs to see how physical effects are changing or how quickly responders are able to move through difficult terrain, and therefore the ICs may be better able to project how the crisis and response may develop (but not all effects are directly visible or visible from certain vantage points).

Research Objectives

The goal of the present study is to examine the impact of real-time imaging feedback on data search and diagnosis in an uncertain and dynamic environment. A growing body of anecdotal evidence from the use of similar systems in other domains suggests that, decision-makers may over-rely on, or fixate on, the real-time imaging rather than use it to compliment or verify other data sources. This over reliance in turn may lead to a narrowing of data search activities and a reduction in hypothesis generation. Therefore, we will examine when and how the new imaging data is accessed for both situation assessment and planning purposes. One concern is that the detailed and real-time nature of this new data source makes it very compelling and thus adversely affects the use, interpretation, and integration of other data available through other channels.

METHODOLOGY

A simulation exercise was developed based on the 1994 accident at the Octel facility in Cheshire, England The use of an actual event as the basis for the simulation helped to ensure its face validity, which is an important factor in eliciting authentic performance from experienced practitioners (Woods and Sarter, 1993; Johansson et al, 2002). This particular event was chosen because of (a) its level of complexity, (b) the availability of post-event analysis and reference materials (Davis, 2002; HSE, 1996), (c) the expectation that the participants would not be familiar with the details of this event, and (d) the scenario could not be understood and managed properly if one only utilized or over relied on data from the image channel.

Participants

Eight volunteers were recruited from the fire service and emergency management agencies of three different counties in Ohio, USA. All were experienced ICs, with between 2 and 16 years (avg. = 6.1) of experience in incident command.

Simulator Set-Up

The simulation exercise was conducted using the IC's workstation at the Butler County, OH EMA Emergency Operations Center (EOC) which provided the standard sources of information used to manage a crisis of this nature, included a geographical map of the facility and surrounding area, a facility-layout map, a status board, which indicated the number and type of assets available and on-site, and material safety data sheets (MSDS), which provide the nature, associated hazards, and recommended tactics to address spills of various chemicals. Weather updates, which included the ambient air temperature, wind speed and direction, and cloud and precipitation conditions were available every 10 minutes.

In addition, a 21" monitor was placed on the left side of the workstation to present the simulated imaging feedback from the UAV (see Figure 1). The UAV imaging was created by digitally enhancing a high-resolution photo of the facility using Fire Studio 3.0 (Digital Combustion) to produce a video-like presentation (see Figure 2). Due to limitations in the simulation software, the imaging data was limited to a fixed view. However, the participants were only informed of this limitation if they asked to modify the vantage point during the simulation.

Procedure

Prior to beginning the exercise, the participants were given time to ensure they were familiar with the equipment and resources available for conducting the operation. They were informed that they could request any additional information they needed, including details on the facility, the chemical processes, and surrounding areas. A series of data cards (see Table 1) were prepared which contained detailed information on the processes and chemical hazards at the facility. The data cards were used to make the ICs data search and integration processes externalized for the research analysis. Note that H5 – H8 relate to potential complications and hazards associated with the presence of liquid ethyl chloride or EC (HCL is hydrochloric acid; BLEVE refers to boiling liquid expanding vapor explosion). Answers to queries outside this data set were relayed through the confederate from the experimenter.

Figure 1. Workstation setup

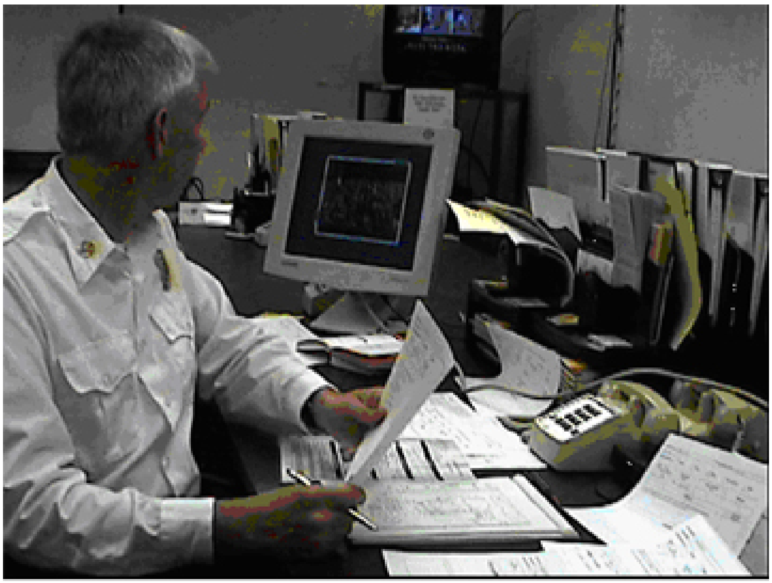


Figure 2. Screen capture of imaging

Table 1. Data cards

Facility data	Hazard data
F1: Chemicals on site	H1: EC reactor contents
F2: Description of surrounding area/population	H2: Vapor hazards
F3: Fire protection systems (cladding, suppression)	H3: EC exposure standard
F4: Types of chemical & processes on site	H4: EC handling
F5: Chlorine storage area description & location	H5: Boiling point of EC
F6: Number of employees	H6: HCL hazard
F7: Hydrology of area	H7: Liquid EC hazards
	H8: BLEVE conditions
	H9: EC environmental effects

At the start of the simulation, a confederate gave the IC a verbal briefing and hardcopy report of the events leading up to that point in time. The confederate also mediated communications and requests between the IC and the simulated on-site responders, facility employees, and outside agencies. The simulation ran for approximately 90 minutes. It should be noted that it ran in real-time, with no "time-outs" or artificial advances in time. A 30-minute debriefing provided an opportunity to further probe any observations from the simulation session and to capture the subjects' thoughts on the use of the new imaging data.

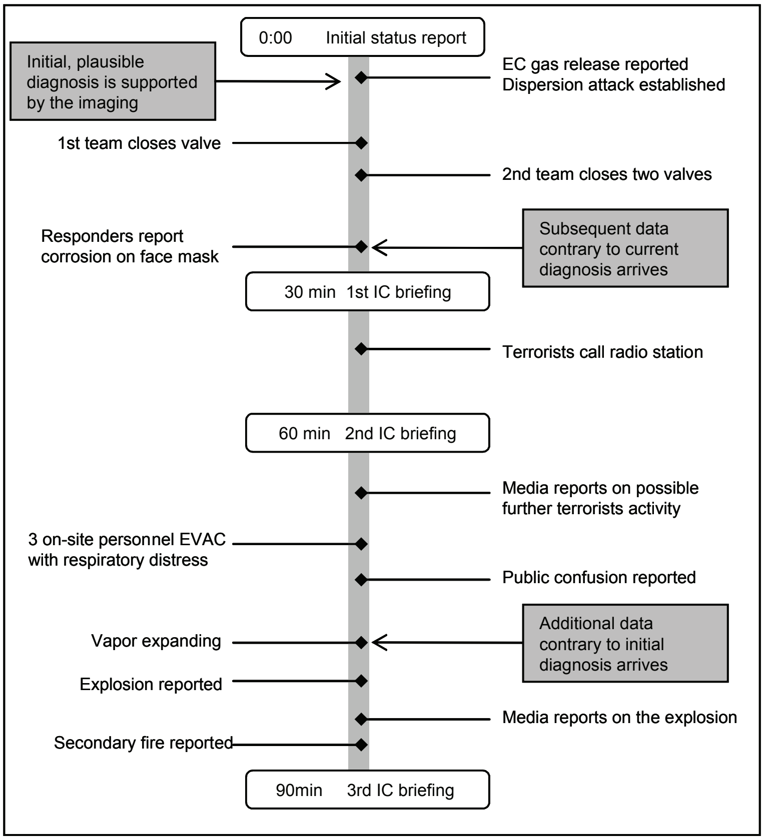
Simulation Scenario

The ICs assumed command of a HAZMAT event at a large petro-chemical processing facility that produces motor fuel anti-knock compounds. There were approximately 300 employees on-site and a residential development 250 meters from the southwest boundary of the facility. A large vapor cloud, was clearly visible in the UAV imaging, was reported to be enveloping an ethyl chloride (EC) processing plant. The second hazard was a large pool of liquid EC collecting near the container tank. However, it was obscured from view by the vapor. The vapor would breach of the facility boundary at the 70-minute mark and if it was not addressed, the liquid EC would ignite and flash back to the storage tank at the 85-minute mark. Figure 3 shows the timeline of key events in the simulation.

Tasks

The ICs had three main tasks during the simulation: diagnose the threat(s), manage the operation, and conduct three verbal staff briefings. Although the briefings were not interrupted, the simulation events did not pause i.e., events, including changes in the smoke pattern or fires, continued to be displayed in real-time on the monitor

Figure 3. Simulation timeline



Diagnose Hazards

The main task was to identify any and all hazard(s) at the facility and to develop a response to contain and minimize the threat(s) to the surrounding population and property.

Manage Operations

As in an actual crisis, the diagnostic task was conducted while also responding, in real-time, to externally-driven events, such as new developments in the situation and fulfilling requests from on-site responders for information, decision-input, or for additional resources (Woods and Hollnagel, 2006). These events were communicated via "injects" which were read to the IC and then presented as a text message by a confederate. Note that the diagnosis and operations management tasks had to be performed concurrently, in that operational demands would occur throughout the simulation. However, while they often represented a source of work, many of the operational events also provided information that could be incorporated into a diagnosis

There were 22 scheduled update reports and 22 requests from the field requiring a response. As much as possible, the scenario was adapted to account for the participant's decisions by discarding a pre-planned message if it became irrelevant as a result of an earlier decision. The ICs had the option of verbalizing their responses, recording them on the message form, or both.

Verbal Briefings

The ICs were required to give three, 3 minute verbal assessment reports as if they were updating the center staff on the state of the event and response, at 30, 60, and 90 minutes into the exercise. The reports needed to include a review of the current state and nature of the hazard(s), the planned response(s) (including resource management recommendations), and how they expected the situation to evolve until their next briefing in 30 minutes.

Performance Standard

Although there was no canonical sequence of actions for properly managing this scenario, a performance standard was developed based on feedback from several subject matter experts. The standard detailed what could be expected from a proficient IC who has been provided with the tools and information contained in the exercise.

All of the information necessary to detect and correctly diagnose the liquid EC hazard, as well as the threat that it presented, was available to the ICs. However, because this information was distributed across different data sources and arrived at different times, it required the IC to use multiple sources and integrate their inputs over time. Because the gas obscured the view of the liquid EC, the imaging would not help in detecting it. Thus an over-reliance on this data source could lead to the erroneous conclusion that the EC gas was the only hazard present.

It should be noted that the gaseous and liquid forms of EC present different hazards and require different response tactics. Ethyl chloride gas can be toxic and is usually addressed with a water-based dispersion attack to lower the concentration level in the atmosphere. Liquid EC is potential a flammable and explosive hazard and is typically addressed with a foam suppression attack. It has a relatively low boiling temperature of 54º F and as it evaporates, it forms a flammable vapor and mist of hydrochloric acid (HCL) vapor, which is highly corrosive. Contact with the water spray from a dispersion attack would actually increase the rate of evaporation thus increasing the amount of flammable gas present. It would also add to the amount of visible vapor present even after all the source valves had been closed.

One verbal report the ICs received from the field stated that after attempting to close one of the main valves responsible for the leaking gas, one of the facility personnel had to be assisted from the area due to corrosion on their face shield. Knowledge of both the boiling point of EC and the new hazard created from its evaporation were important in the simulation because the ambient air temperature rose from 43º F to 54º F during the course of the scenario.

Data Collection and Analysis

Audio and video recordings were made of each session. Verbal and behavioral protocols from these recordings were then used to develop a process trace of each IC's performance (Woods, 1993; Woods et al., 1994; Dekker, 2002). In addition to evaluating the accuracy of their assessments, the protocols were also used to analyze the comprehensiveness of the participants' use of available/relevant data and their skepticism about the fidelity of the data and its source. The tactics used by the IC during the simulation, as well as the content of their situation assessments, provided converging evidence regarding their diagnosis of the situation.

RESULTS

All of the ICs acted on the initial assessment report and ordered a dispersion attack with water cannons to prevent the spread of the EC gas beyond the facility boundaries. This is the appropriate response given information available at the start of the scenario. During his first briefing IC#4 identified the flammable liquid hazard from the EC collecting near the storage unit, and initiated a foam suppression attack to address it. None of the other ICs referred to this potential threat or prepared for this contingency. Only one other IC (IC#1) inquired about the availability of suppressant foam; however, during the debriefing, he indicated that this was a precautionary measure only and not tied to any identified threat. This surprising result suggests that none of the remaining ICs found information or detected any anomalies in the evolution of the crisis that would indicate the need to modify the initial assessment of the situation.

Patterns in Data Search Strategies

A review of the ICs' data requests was performed in order to determine if any patterns existed that correlate to their performance in the diagnosis task. Tables 2 and 3 show which of the facility and hazard data cards were selected by each of the ICs. The subjects are grouped according to which cards they selected with IC#4's selections highlighted for comparison. Clearly the fact that an IC did not request a specific piece of information does not necessarily mean that they did not possess it through some other means, i.e., prior experience. Therefore it was important to analyze these results in the context of the planning and assessments as described below.

Table 2 shows that IC#4's facility data requests were not unique. In fact, details about the on-site chemicals, processes, and fire protection systems as well as the surrounding population (F1through F4) were universally selected. ICs 1, 4, and 5 also requested additional information on the nature of the chlorine storage facility and its location (F5).

Table 3 shows a more interesting difference between IC#4's data requests and the rest of the ICs with regards to the search of chemical hazard data. Only IC#4 requested information about the boiling point of EC and the potential hazards of liquid ethyl chloride (H5 and H7).

A separate review was also conducted to elicit any patterns specific to the use of the imaging, including the timing and relative frequency of sampling and if it was coordinated with other data sources. Although eye tracking data was not collected, analysis of the behavioral protocols indicates that IC#4 sampled the imaging less frequently and he tended to sample it only during relatively low tempo periods, i.e., when no updates or external demands had recently been received. In contrast, the other ICs would often reference the monitor when a verbal update arrived and attempt to locate the position of the event being reported on the screen.

Situation Assessments

Situation assessment in incident command is an example of inferential analysis in which the decision-maker must often develop a suitable explanation for uncertain, incomplete, and contradictory information, and adopt a course

Table 2. Facility data card requests

Facility data	Subject number							
	4	1	5	2	7	3	6	8
F1: Chemicals on site	♦	♦	♦	♦	♦	♦	♦	♦
F2: Description of surrounding area and population	♦	♦	♦	♦	♦	♦	♦	♦
F3: Fire protection systems	♦	♦	♦	♦	♦	♦	♦	♦
F4: Description of the chemical processes at plant	♦	♦	♦	♦	♦	♦	♦	♦
F5: Description of the chlorine storage area	♦	♦	♦					
F6: Number of employees at facility						♦	♦	♦
F7: Hydrology of area								

Table 3. Chemical hazard data card requests

Facility data	Subject number							
	4	1	2	5	3	8	6	7
H1: EC reactor contents	♦	♦	♦	♦	♦	♦	♦	♦
H2: EC vapor hazards	♦	♦	♦	♦	♦	♦	♦	♦
H3: EC exposure standard		♦	♦	♦			♦	
H4: EC handling procedure	♦	♦	♦	♦				
H5: Boiling point of EC	♦							
H6: Hazards associated with HCL		♦						♦
H7: Hazards associated with liquid EC	♦							
H8: BLEVE conditions								
H9: Environmental impact of EC								

of action that is as flexible, adaptive, and robust as possible (Patterson et al., 2001).

A review of the protocols from the twenty-four verbal reports indicates that none of the ICs except #4 revised their situation assessments to include additional hazards beyond the toxic gas release. This is indicated by the lack of any direct references to additional potential hazards, but also in the preparations and contingency plans they developed. A review of IC#4's protocols, as shown in Table 4, also reveals that although there was significant overlap in the data requested, he consistently requested verification of the data as well as the underlying assumptions associated with it (particularly if it did not originate from fire service personnel). For example, while referencing the MSDS (material safety data sheets) to verify the response strategy employed by the facility personnel, he noted the low boiling point of liquid EC. Although the presence of liquid EC was not indicated in the initial briefing, this cross-check of the response strategy yielded data that, in conjunction with other information, supported another hypothesis and line of reasoning.

Table 4. Protocol excerpt from IC#4 assessment #1

Actions/Dialogue	Commentary
Requests updates from the plant and local hospitals. "Do we have any casualties reported?"	The requested information aids in assessing the scope and scale of the situation.
Initially looks at display, then refers to the facility map to orient, then back to monitor. "OK, its just the cloud. Looks like it's headed…what direction is that? OK, east towards the town.	Coordinating the map and imaging compass headings and establishing reference points.
Turns from the monitor and reviews the listing of chemicals used and processes conducted at the plant. Requests updates from the site and facility information. "It's a chlorine plant, wow, chlorine is the worst. That's going back to the fire liaison for information about how those (chemicals) can affect each other and if the chlorine has been affected at this point..."	Gathering data from multiple sources to model and anticipate possible interactions and future developments.
Sweeps hand over the monitor in the direction of the town "We'll need to evacuate that area. I'll have my HAZAT guy determine the area (to evacuate)".	Establishes a plan of action for the current threat. Defers to staff member to work out details.

Table 5 provides an excerpt from IC#3's final assessment but it provides a sample of the type of dialogue observed in the other ICs' (except #4) reports. It suggests that the ICs' tended to focus more on the physical and spatial relationships to a greater degree than IC#4. In contrast, IC#4 appears to have focused more on the functional relationships and interactions between elements in the EC processing system.

DISCUSSION

The main tasks in the exercise were to correctly identify all of the hazards and to apply the appropriate responses as quickly as possible. Only one of the ICs maintained a broad data search strategy and revised the initial, erroneous assumption that only one hazard was present.

The scenario in this simulation was what Johnson et al (1988) described as a "garden path" problem. In these cases, the early, highly salient cues point to a plausible, but incomplete, or incorrect assessment, while later, less salient cues point to the correct assessment. Garden path problems can lead to a "this and nothing else" fixation in which the operator is unable to realize the need to revise his/her assessment and to deviate from the original plan (De Keyser and Woods, 1990). In fixations, conflicting or inconsistent information is discounted or missed leading to failures to revise assessments, hypotheses, and plans. Studies of inferential analysis indicate that errors in handling garden path problems derive from premature closure of the analysis and hypothesis exploration process (Patterson et al, 2001).

In order to guard against going down the "garden path", it is important to maintain a broad search of relevant data sources and to also perform crosschecks between these data sources. Crosschecking can often reveal inconsistencies between data sources, which may indicate flaws in the current analysis (Patterson et al., 2004; Elm et al., 2005; Grossman et al., 2007). Recall that the initial assessment provided by the facility staff indicated that a toxic vapor release

Table 5. Protocol excerpt from IC#3 assessment #3

***Actions*/Dialogue**	**Commentary**
Sweeps hand over the center of the display "I've got the plant evacuated" *Pulls hand away from monitor* "My firefighters are backed off" *Sweeps hand around the monitor* "The community has been evacuated"	Appears focused on spatial relationships with the monitor as the sole reference.
Points to the site of the EC leak at lower right hand corner of the display "I've got water going on the leak and on the tanks"	
"Looks like we're spreading…is that another fire?"	Observes a new fire near the EC leak and terminates report.

had occurred, which, while not erroneous, was an incomplete description of the problem. The imaging supported this incomplete assessment not only by highlighting the vapor hazard, but also by masking other relevant cues, such as a pool of liquid EC at the base of the processing plant. Therefore, additional sources of information needed to be accessed to obtain the correct and complete assessment of the incident.

Seeing is Believing?

Due to the nature of their work, and their extensive field experience, ICs typically place a high level of trust in visual evidence and in their ability to evaluate a situation based on direct, visual observation (Page, 2005). It has also been suggested that the fire service's emphasis on a "hands on approach" engenders a belief that "seeing is believing" (Gilchrist, 2000; Page, 2005). Therefore it is possible that the more familiar format of the imagining garnered greater trust, than the other sources of information data. Compared to verbal messages, which are transient in nature, and textual data, which can be obscured or misplaced at a workstation, the real-time imaging was continuously available to the IC and easily observable. Thus, it could be argued that it was highly salient relative to the other information sources, and gave users the sense that it provided a more complete picture than

However, while it afforded the ability to see spatial relationships, it did not reveal functional relationships and therefore, did not contain all of the necessary information. It is possible that the "seeing is believing" heuristic led to a "surface/deep" oversimplification in which an emphasis is given to the interpretation afforded by surface cues, when in reality, a deeper search is required to uncover important cues (Feltovich et al, 1997). With an unprocessed image, the task of detecting the relevant cues from the context-rich, detailed background is left to the observer, as IC#4 comments:

"I found it distracting to corroborate this (map of the facility) and the video - both because they're not to scale and they differ. It was simpler to look at the map because it's all theory; it's all strategy". – IC #4

In this case the terms "theory" and "strategy" seem to suggest that the more abstract line drawing allowed greater focus on the relevant relationships directly related to the command center task at hand, which in this case was looking ahead at planning of a potential evacuation.

Timing is Everything

In highly dynamic environments, the perceived value of information is highly correlated with its currency, or as one IC commented: “newest equals best”. In other words, the latest updates provide the most relevant information. It is clear that order to define a problem in a dynamic environment, the decision-maker needs information about any changes in the world that may impact the validity of their model and redefine what viable options exist. For example, physical maps of the incident area are typically used to plan the routing and positioning of resources relative to the area of interest. However, because they depict conditions prior to the incident, local operators must often adapt or even discard their initial plans due to unforeseen circumstances, such as restricted access or other unexpected hazards.

The reasonable assumption made by the ICs was that the real-time imaging addressed this deficiency and was accurately reflecting the current state of the situation. As summarize in this debriefing comment:

“The (paper) map obviously wasn’t accurate. Once that gets to a certain point, it becomes distracting. This (the monitor) was accurate; you can’t dispute that.” The video can never be obsolete.” – IC#6

It is possible that the perceived value of the imaging data, and thus its dominance in framing the problem for the ICs, was related to the fact that it was unprocessed, unfiltered, and (un)-delayed. It provided more, and more current information directly to the IC in an environment where information often arrives slowly and is dependent on mediation through (several) other individuals.

The bottom line result of the study is that 7 of the 8 incident commanders over-relied on the information available through the imaging channel. The ICs did not balance their information search across all data channels and missed important information, nor did they crosscheck their assessment sufficiently using other data channels. This study provides the first empirical confirmation of the observations and reports from the field that command center personnel can be captured by the video feeds from UAV resources and over-rely on the information available from that source and undervalue or miss information only available from other sources.

The study indicates that the new technological resource while providing benefits also creates new vulnerabilities (Woods et al., 1994). The design challenge is to preserve the benefits while providing new visualizations or other mechanisms that help incident command to balance information search over all of the data channels/information resources available, to better cross-check sources and findings in order to revise assessments, and to avoid premature narrowing in on one assessment or hypothesis (Woods and Hollnagel, 2006). For example, new visualizations could encourage a more balanced monitoring over data sources, new analytic tools can suggest areas where cross-checks may be needed or fruitful. Developing interactive critiquing system could encourage the exploration of alternative hypotheses and enhance anomaly detection (Smith et al., 1997). Aids for sense making, such perspective taking tools, can help commanders stay close to the scene of action via imaging channels while helping them step back to maintain a global, anticipatory and strategic perspective. The scenario simulation/garden path problem itself could serve as the basis for a training module designed to help incident commands practice better information search and integration by confronting some of the vulnerabilities that could trap them.

Methodological Considerations

Some shortcomings in the present study warrant discussion. Although we attempted to externalize IC reasoning through the briefing task, it may not have fully captured their thinking given the time pressure imposed by the simulation. While time-out could be granted to reduce this problem, such an artificial interruption would partially negate the realistic level of time pressure in the current design, and it can be difficult to accurately assess retrospective explanation with a debriefing interview.

It is possible that the novelty of the imaging feed could have made the ICs more likely to use information available through the imaging in developing their assessment and planning activities. On the other hand, they have much more experience using more traditional data sources. In addition, the image source (the simulated UAV) was not controllable. If the ICs had the ability to alter the perspective view, they could have been drawn more deeply into the 'picture' provided by that source to the exclusion of information available only through other channels.

Future Work

Emergency management is an example of what Wærn (1998) termed *cooperative process management,* in which operators must cooperate in order to supervise and control a highly dynamic situation. This new source of feedback also has the ability to provide distributed team members with a common (visual) frame of reference. Therefore, one extension of this work would be to explore how a team, particularly one with non co-located members, might employ this technology to support collaborative work. In addition to being a more realistic setting, the dialogues and interactions that occur in a team setting would promote the externalization of hypotheses and the underlying rationales, i.e., what data or feedback is being used as support (Clark and Wilkes-Gibbs, 1986).

Additional work will also be needed to understand how to take advantage of this new resource while overcoming the new risks it presents. In particular, it will be important to focus on supporting the balanced integration of all data sources in order to detect inconsistencies, which can reveal flaws in the current situation assessment. Conversely, a balanced approach to data collection and analysis can also provide evidence of when there is agreement between multiple sources and thus support the current assessment.

CONCLUSION

This study provides initial, empirical evidence to support anecdotal reports that real-time, image-based feedback can have an adverse effect on data search and analysis activities. The results suggest that this new resource, while holding promise for supporting information analysis, can also have a strong framing effect, which can result in a pre-mature narrowing of both data search activities and the exploration of a solution space. Similar effects have been observed in other domains, particularly in military command and control and in intelligence analysis (Patterson et al, 2001).

Although all levels of command can now be supplied with the same image-based feedback in real-time, its value to decision-makes at those different levels, and the methods in which it should be utilized, are different. While direct observation of an area of interest can reveal some spatial relationships, this information still must often be abstracted into a form that can be used for planning purposes.

This research was intended to help Emergency Management Agencies and Incident commanders identify and better understand the consequences of introducing this new resource into the command and control loop and the potential impact of introducing similar technologies on training and operational procedures. However, it is hoped that this work will also contribute to the general knowledge base of technology-mediated decision-making in information-rich, high-tempo environments.

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