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Probing PROBE: A Field Study of an Advanced Decision-Support Prototype for Managing Chemical, Biological, Radiological, Nuclear and Explosives (CBRNE) Events

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The purpose of this field study was to investigate teamwork and communication among event management personnels and to assess the degree to which PROBE, the advanced prototype they were using to manage a Chemical, Biological, Radiological, Nuclear and Explosives (CBRNE) simulation, would adequately meet their needs. The study was a continuation of previous research conducted in the early phase of the PROBE development. From the verbatim transcripts, two communication-related analyses were applied to identify the instances of effective and ineffective communications among the management team. These revealed that communication was mostly effective. However, a serious communication breakdown that was observed could have had fatal consequences. It showed that great care must be taken to ensure the safety of first responders at all times when evaluating prototypes in the field. A checklist was generated from the lessons learned in to assist future researchers to prepare for CBRNE-field studies.

Categories and subject descriptors: management decision-support system; teamwork; communication

Keywords: teamwork; communication; management decision-support system

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1. INTRODUCTION

Emergency services responders deal with several types of emergencies as part of their normal, daily routines (Kuban et al., 2001). For example, the discovery of an unattended brown parcel left at an airport may lead to its immediate closure; departures are postponed until further notice, arrivals are rerouted, people are evacuated and luggage service is halted, all of which are both time-consuming and very costly (Stojmenovic et al., 2011). The unpredictable contents of the parcel, and hence the possible safety-related consequences, make it difficult to manage such an event. The management of Chemical, Biological, Radiological, Nuclear and Explosives (CBRNE) events is highly complex; it includes, and goes beyond, crisis management in search and rescue situations, emergency medical events or hazard mitigation (Waugh and Streib, 2006). Many professionals representing different agencies and disciplines are involved in the CBRNE event management, including police, fire department and emergency medical services (EMSs; Simpson and Hancock, 2009). They all need to work closely together as a team in order to successfully manage a timely response to a potentially criminal action that may be, or that could escalate to become, very large and very dangerous.

Amid the chaos in a CBRNE event environment, and with the physical distance between different responders and responder groups, communication breakdowns are likely to occur because so much is happening simultaneously. Everyone in the command post is receiving information from different sources and from different technologies. Thus, for example, appointed first responders in the field are updating their team leader in the command post through radio; members of the command post are coordinating resources with dispatch using phone and communicating with the incident commander (IC) in face-to-face interactions. In very large events involving mass casualties, public health authorities, surrounding hospitals and makeshift field hospitals, other personnels may also be directly involved in the event management. The wide variety of communication modes and technologies can lead to misunderstandings and incorrect actions; some of which could potentially have fatal consequences.

The CBRNE simulation described here was part of a large project sponsored by the CBRNE Research and Technology Initiative and carried out in partnership with a team of experts representing a wide variety of organizations. These include the Royal Canadian Mounted Police—Canadian Bomb Data Centre, The National Research Council—Canadian Police Research Centre, the Department of National Defence—Defence R&D Canada and Director General Nuclear Safety, Carleton University—HOTLab, Loraday Environmental Products Ltd., International Safety Research Inc., responder teams from seven major Canadian Centres and the AMITA Corporation (Amita, 2008). The present research is a continuation of the work conducted in the earlier phase of the development of PROBE used here (Lindgaard et al., 2009).

The remainder of the paper is organized as follows. The next section discusses the responsibilities of an emergency response team. This is followed by CBRNE management and structure. The introduction then concludes with a brief outline of the evolving software used in this CBRNE simulation. The theoretical section begins with a discussion of distributed cognition and cognitive ethnography. This is followed by a discussion of teamwork and communication. Next, two analysis methods used in this paper are discussed, concluding the theoretical section. The results of the two analysis methods are presented thereafter, followed by the general discussion and conclusion sections.

1.1. Responsibilities of an emergency response team

CBRNE emergency response teams typically include EMS, teams comprising different police specialists and teams of fire fighters including hazardous material technicians (hazmat). Each team has very specific and different responsibilities that all have to come together in a coordinated fashion so as to effectively manage the adverse event. All responders receive domain-specific training in addition to specialized CBRNE training. The role of the EMS team is to take the vital signs of CBRNE first responders who are about to enter the so-called 'hot zone' containing the offending agent(s) or object(s) (May, 2009; Humphrey and Adams, 2011). Vital signs usually include heart rate, blood pressure, body temperature and respiration rate. The EMS team also performs triage, reporting the types of symptoms casualties, experience to their command post-team leader, and they assess the severity of injuries as well as forwarding casualties to nearby hospitals for treatment once they have been decontaminated. The police team consists of bomb technicians, the forensic identification section (also referred to as FIS or Ident) and generalists. Bomb technicians are included if it is suspected that explosives are involved. Their job is to disable the bomb to prevent it from detonating. Ident officers are responsible for collecting and cataloguing evidence from the scene to document any proof, in case the event is likely to result in a future criminal court case (Reutter et al., 2010). Generalists help to organize the refuge of hostages and casualties; they seal off the entire area and help to keep public order, for example, by redirecting traffic. The hazardous materials (hazmat) team comprises firefighters with specialized training. This group deals primarily with sampling and testing harmful chemical agents enabling their team to identify and neutralize these. Besides controlling the entry into, and exit from, the hot zone, the hazmat team is responsible for setting up and managing a decontamination site to neutralize whatever damage might have been done to people, equipment and property if a harmful chemical is involved (May, 2009). Once the command post members consider the site safe for forensic processing, and the Ident officers have acquired all the necessary evidence from the hot zone, the hazmat team's decontaminate and clean the entire area.

1.2. CBRNE management and team structure

The CBRNE event response team is comprises of a chain of command of responders with different responsibilities (Humphrey and Adams, 2011). The structure of each event varies as a function of its size and complexity (Owen et al., 2008), and in many situations one person may perform multiple roles. In the Province of Ontario, Canada, there are up to three levels of operational response, depending on the magnitude and severity of the emergency and thus on the number of personnels required to respond (Emergency Management Ontario Ministry of Community Safety and Correctional Services, 2008). As shown in Fig. 1, the first responders deal with the dangerous situation in the hot zone in a hands-on manner. The responder team typically includes EMS paramedics, generalists, bomb technicians, Ident and forensic officers, firefighters and hazmat technicians (Van der Kleij et al., 2009).

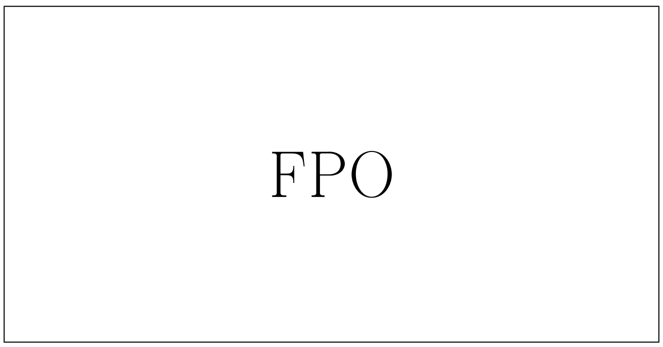

Figure 1. Response structure and positioning in the three zones. FR, first responders.

In larger events, the first responders report to their Ops officers who, in turn, report to their commanders, as shown in Fig. 1. In such cases, Ops teams representing each of the three agencies are set-up in different designated areas in the 'warm zone', the area directly surrounding the hot zone but that is not in immediate danger (Humphrey and Adams, 2011). The decontamination tent is also set up there and bridges to the cold zone. The Ops officers all work together to create and implement an incident action plan (Emergency Management Ontario Ministry of Community Safety and Correctional Services, 2008, 2009), which is a short-term to-do list. Ops officers manage the first responders in the hot zone and manage the deployed equipment, and they are responsible for keeping the commanders in the command post up-to-date Emergency Management Ontario Ministry of Community Safety and Correctional Services (2008), (2009); (May, 2009). In smaller, less complex events, no Ops officers are required, and members of the command post adopt the Ops officers' responsibilities instead. The simulation on which the present research was based include an Ops layer.

In any CBRNE event, the command post is always located in the cold zone or even further away from the scene, for the safety of the commanders. They are often also in contact with representatives from other agencies that only take part in event management under special circumstances (e.g. Health Canada, Public Safety Canada). The command post-team's objectives are to coordinate the emergency response to preserve life, maximize safety and diminish the threat while protecting the affected property, minimizing cross contamination, as well as preserving and collecting evidence (May, 2009). Commanders approve the incident action plan Emergency Management Ontario Ministry of Community Safety and Correctional Services (2008), (2009); they oversee their own agency's progress throughout the event response and are responsible for coordinating their agency's actions with the others. In addition, commanders are in charge of identifying and resolving response issues (e.g. a lack of equipment on site), providing advice to responders and implementing the action plan Emergency Management Ontario Ministry of Community Safety and Correctional Services (2008), (2009). There are usually at least three commanders in the command post, one representing each of the police, fire and EMS agencies. Commanders also determine the level of personal protective equipment (PPE) that responders and casualties need to wear in the hot zone.

The IC is in charge of coordinating all participating professionals (Moynihan, 2009); (EMSs; Simpson and Hancock, 2009). The IC communicates with, and gives orders to, all officers in the event. In addition, he or she can veto the incident action plan and, in some cases, their approval might also be necessary. If the action plan is vetoed, the IC is responsible for providing alternatives (Jederberg et al., 2002). Ideally, the IC is even further removed from the hot zone and separated from the command post for safety reasons. However, the IC usually spends a great deal of time with the commanders in the command post.

As the command post-team makes the crucial strategic event management decisions, it is considered the most important team. Therefore, this research focused on that team.

1.3. Brief outline of PROBE and accompanying applications

PROBE is a CBRNE management decision-support system. Its purpose is to aid interoperability among the response agencies by recording, storing and sharing CBRNE event information (Amita, 2008). The user population comprises predominantly commanders and operations officers involved in the event management. PROBE provides a suite of CBRNE management applications, CBRNE databases, standardized forms, automated evidence collection using RFID tags and information on patient triage. The suite includes applications for hazmat technicians, for example, the chemical biological response aid, a large chemical database that includes another application, PALM Emergency Action for Chemical-WMD (PEAC-WMD). It stores information on chemicals that help to identify and render CBRNE materials safe (Amita, 2008). To support the bomb technicians, Socius, a database in which RCMP bomb technicians enter and store textual and photographic records of incidents involving explosive devices (Amita, 2008), is already fully functional. Finally, the Rapid Triage Management Workbench (RTMW) and the Medical Command Post (MedPost) are designed to support EMS efforts. The RTMW (Moynihan, 2009), shown in Fig. 2, tracks casualty information in one central database allowing all treatment centres, alternate care facilities and hospitals to work with the same information. The MedPost application, an overview which is shown in Fig. 3, is designed to help medical decision-makers gain access to timely and accurate medical information in their effort to save lives. As the figure shows, it provides caregivers with a higher level view, helping them to identify, isolate and manage disease outbreaks and alert public health communities, as necessary, regardless of the magnitude of the event. It is thus particularly useful in the face of a potential radiological or nuclear threat.

In addition to linking all of these applications, PROBE will also be capable of supplementing real-time communication across agencies. This is especially important for the commanders located in the command post where it is often very busy and noisy, with multiple radios going simultaneously, and people coming and going. The mode of communication is predominantly face-to-face and via radio (Humphrey and Adams, 2011). PROBE will not replace the radios. Rather, it records and integrates communications and information during a CBRNE event, which also helps the commanders to produce their incident report after the event.

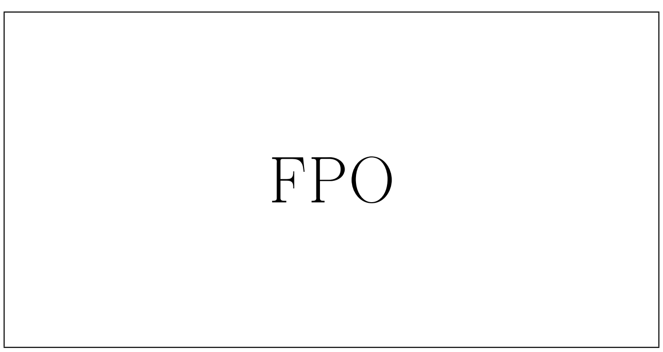

Figure 2. An overview of the RTMW software.

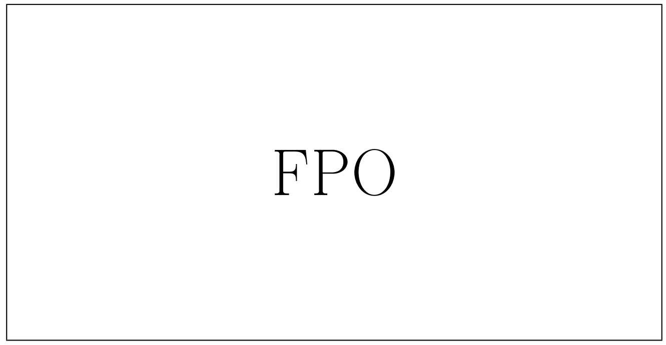

Figure 3. An overview of the MedPost system.

2. THEORETICAL FRAMEWORK: DISTRIBUTED COGNITION AND COGNITIVE ETHNOGRAPHY

In the late 1980s, Hutchins examined the phenomenon of shared knowledge and proposed what he called distributed cognition (Hutchins, 1995). According to this framework, knowledge and thought processes are shared between an individual and the individual's social (i.e. other people) and physical (i.e. tools and artefacts) environments (Hollan et al., 2000). The aim is to explain the interactions and exchanges of information between the individual and these environments. When investigating group work, researchers examine people's activities, communications and artefact interactions through detailed ethnographic study (Rogers, 2006). Studying the interactions between people and technology is fruitful for understanding the role and function of the relevant technology (Rogers and Brignull, 2003); (Kirsh, 2004). Hutchins also coined the term 'Cognitive Ethnography', in which a researcher spends a lot of time in the field (Lewis, 1985). Cognitive ethnography provides data that can then be explained by distributed cognition (Hollan et al., 2000). It assumes that human communication and activity, including breakdowns, are meaningful and culturally determined. Cognitive ethnography was useful in the present research (Dubbels, 2011), as it allows for analysis of the way artefacts are used (Williams, 2006). Distributed cognition and cognitive ethnography were therefore employed in the data collection process.

2.1. Teamwork and communication

Given that different agencies share the management of CBRNE events, excellent teamwork is essential. Teamwork is the interaction of two or more individuals working together to accomplish a common goal (Kozlowski and Bell, 2003) which, in the CBRNE event, is the management of the crisis (Moynihan, 2009). To manage an event effectively, each team member is assigned specific tasks, much like each agency's responsibilities are divided among its members. Effective team coordination and collaboration (Reddy and Spence, 2008) involving extensive information exchange (Mickan and Rodger, 2005) is essential to accomplish those tasks. Communication enables the planning of actions and the forwarding of updates to alter action plans (Hazlehurst et al., 2007), and it can also help teams recover from interruptions (Orasanu, 1994). Teamwork effectiveness can be measured by examining communication between team members (Bowers, 1998).

Instances of communication can vary in effectiveness. Communication is effective when the meaning of a message is successfully conveyed from speaker to listener. Closed loop is one of the most common examples of effective communication. It comprises three main parts: (i) the speaker initiates a message; (ii) the intended listener receives, interprets and acknowledges receipt of the message and (iii) the speaker ensures correct reception and interpretation of the message (Salas et al., 2009). In a CBRNE command post, an instance of closed-loop communication could be something like this: the hazmat commander tells the EMS commander that there are 20 casualties in the hot zone; the EMS commander responds that he will send the paramedics in, and the hazmat commander closes the loop by saying 'O.K.'. Closed-loop communication is a good indicator of successful teamwork leading to successful team performance. For the purpose of this research, instances of effective communication were operationalized as closed-loop communication.

Communication breakdowns are defined as faulty verbal interactions and appear in the forms of ineffective timing (i.e. late), incomplete and/or inaccurate content and key individuals not being informed (Lingard et al., 2004). Breakdowns are important indicators of teamwork effectiveness and hence also of team performance. Interruptions are one type of essential breakdowns in the CBRNE event because they often update team members on the constantly changing environment, enabling them to fine-tune the management of their response. Indeed, there would be little or no progress in the shared understanding and knowledge of the event without interruptions. However, the effectiveness of the event management could suffer when an interruption is not managed appropriately, for example, in the event of an incomplete or inaccurate update, or when an important issue noted earlier has been forgotten. A command post member whose attention is constantly shifting between her radio and her command post-team members may not have all current status information of the event. Information communicated among commanders may be incorrect, and/or messages may be overlooked, missed or forgotten, all of which may decrease the effectiveness of the emergency response.

Open loop is another example of ineffective communication. It can occur when a speaker initiates a message, for example, a question, which is then either not received, not interpreted, acknowledged or answered (Salas et al., 2009). Communication breakdowns such as open looped communications increase the probability of errors. For the purpose of this research, several types of ineffective communication were analysed, including ineffective timing, key individuals not being informed and open-loop communication.

To gain an understanding of teamwork and communication, one first needs to identify where, when, why and how often different communication breakdowns are likely to occur, along with other errors in event management most readily uncovered by examining communication breakdowns. Two communication aspects were important in this research, namely the types of utterances and the topics of communication. Communication analysis and content analysis were therefore applied to the data.

2.2. Communication analysis

Communication analysis involves the categorization of the topic (e.g. equipment, personnel, etc.) and the type of utterance (e.g. question, answer, etc.; (Kramer, 2009); (Parush et al., 2011). (Hazlehurst et al., 2007) studied coordination and collaboration among team members in a hospital environment by focusing their analysis solely on the type of verbal exchange. This was done here as well. The type of utterance helps to understand the information flow by demonstrating when information is needed (e.g. question) and when it is being shared (e.g. update). Sequences of communication types were examined for effective and ineffective communications.

2.3. Content analysis

Content analysis is a widely used technique (Hsieh and Shannon, 2005). The communication topic is another aspect necessary for a thorough assessment of communication and teamwork in the command post. In latent inductive analysis, a researcher gradually generates topic categories, as they emerge from the data. Here, evidence of communication breakdowns was uncovered to understand communication and teamwork in the CBRNE event management environment.

3. METHOD

3.1. Participants

A total of 14 experts participated in the study, representing 3 hazmat experts, 3 EMS officers, 3 police officers, 2 PROBE scribes, 2 event coordinators and 1 software developer for PROBE. Of these, five were in the command post (one EMS, one hazmat commander and his scribe, the police department IC commander and his scribe), and three were Ops officers (one per agency). The scribes' role was to transcribe into PROBE what the commanders communicated to other members of the response team. While the IC was in charge of managing the CBRNE event, the event coordinators were in charge of managing the logistics such as monitoring the progression of the scenario and planning lunch. Participation in the simulation was a part of their normal day jobs; permission for the researchers to be present had been granted *a priori* by all concerned.

3.2. Design

Two researchers located in the command post observed the command post-team members during the simulation, from opposite sides of the room.

3.3. Apparatus

Each researcher was equipped with a video camera (Sony Handycam DCR-SR-300 HDD) and three stationary audio recorders (Olympus WS-311M Digital Voice Recorder) were located in different areas of the command post in which four laptop computers were set up (one per EMS, hazmat, police; one for the IC). Each commander's radio was running at a unique frequency. An additional radio allowed the commanders to listen to communication between the Ops officers located in different areas of the warm zone. As far as possible, these conversations were captured. Verbatim utterance transcriptions were transferred to NVivo 9.0 for further analyses.

3.4. Procedure

The event organizers first explained to the participants about the purpose of the researchers' presence and task. Then, participants read and signed the ethics approved informed consent form before the researchers proceed to the command post for their observations. All verbal interactions in person, radio and software communications were recorded. At the end of the event, all commanders were given debriefing forms, thanking them for participating. Finally, a briefing session was held for all the expert participants.

3.5. Data analysis

In an effort to reconstruct the entire event, all video and audio recordings were transcribed *ad verbatim* and merged into a single file to compare activities across all command post-team members. Recordings were viewed multiple times to identify and verify the identity of the speakers and listeners of verbal communications. To focus the analysis, any talk unrelated to the event management was removed from the transcript.

Table 1 shows the minute-by-minute formatting of the transcript. The leftmost column shows the time of observations, followed by the source of the original data (video/audio/notes). The three rightmost columns show the data obtained from each agency. All utterances were coded digitally. For the communication analysis, the researcher focussed on the types of utterances and on the communication topics and contents in the latent inductive content analysis. Meaning was extrapolated from the categories to identify and compare instances of effective and ineffective communications. To allow the calculation of the inter-rater reliability of both analysis methods, another researcher independently categorized each sentence from a randomly selected 10% of the transcript by the type and content of communication using Cohen's kappa. This result is reported; any disagreements between the two raters were settled by negotiation.

4. RESULTS

The results are presented in the following sections. A description of the event is provided first, followed by the communication analysis findings reporting instances of effective and ineffective communications. Next, the latent inductive content analysis results are shown in which the severity of ineffective communications was assessed. Then, the inter-rater reliability of the two analysis methods is presented. Thereafter, a summary of communication and teamwork is presented, and finally the CBRNE simulation event management goals are outlined.

Table 1. Format of the transcript used for data analysis.

Time	Source	EMS	Police	Hazmat
10:33	Video File: 141203	Radio 1 (X): Can I get an update on XYZ? X (Radio): Yea, XYZ has been ordered and is on the way	Z (Radio 3): It's green and blue	Radio 2 (Y): Exercise, exercise exercise—Haz responding
10:34		Radio 1 (X): Thank you	Right?	

4.1. Event description

According to the scenario prepared for the simulation, police officers were said to have found a makeshift lab in one of the on-site storage containers in the Port of Saint John. This area was labelled the hot zone. A command post was set-up to manage the emergency response from the cold zone. The data were divided into two phases, comprising approximately an hour and a half each, because two separate incident action plans were prepared during the simulation. Phase 1 was executed as the first group of responders went into the hot zone to gather information on the severity and magnitude of the situation. They found hydrochloric acid and potassium cyanide. Later, an activated bomb was detected as well. Phase 1 therefore ended with the deactivation of the bomb and the removal of casualties from the hot zone. Phase 2 involved the planning and execution of the second incident action plan, for the re-entry of police and hazmat first responders into the hot zone for evidence collection and clean-up. EMS officers remained on standby in the warm zone, just in case.

4.2. Communication analysis results

The communication analysis, divided into two steps, focussed on utterance types. In the first step, each utterance was coded by type, as these emerged from the raw transcript data. The second step identified the sequences of effective and ineffective communications.

4.2.1. Step 1: coding results

Some 15 categories emerged from the transcript, as seen in the leftmost column of Table 2. Definitions are given in the middle column, and the rightmost column gives examples of the utterance types uncovered.

There were a total of 1897 utterances in the entire simulation. The volume of communication was fairly similar in Phases 1 and 2. Anecdotally, there seemed to be more activity in Phase 1 in which the most dangerous parts of the event were handled: the chemical was neutralized, victims were found and removed from the hot zone and the bomb was deactivated. One would have expected a high frequency of communication, allowing commanders to organize the response, leaving little need for activity in Phase 2. However, the commanders were more involved in altering the second incident action plan for re-entry into the hot zone for clean-up and evidence collection than for the first incident action plan.

The most frequent utterance types were questions, statements, answers and acknowledgments.

Questions were expected to comprise the most frequent type of utterance because the intense decision-making efforts require individuals to obtain and share information. If important information necessary to make the correct decision about a plan of action is missing, then the only way to proceed is to ask a question to obtain that information.

Answers were also among the most frequently occurring utterance types. If all communications had been closed loop, the number of questions and answers should have been almost equal. Instead, several instances of ineffective, open-loop communication were uncovered. These are discussed later.

Statements included all facts and ideas which were verbalized very frequently.

Explanations were elaborations on any utterance, raising their frequency as many utterances such as answers and statements was elaborated upon by explanations.

Acknowledgments also occurred frequently, possibly because acknowledgments were universal responses to all types of utterances, except attention requests and questions, informing the speaker that the listener had received the message. Because communication analysis requires categorization of each utterance in isolation, it leaves the analysis devoid of context, prompting analysis of utterance sequences, described later.

Repetitions and updates occurred with medium-to-low frequency when a responder forwarded newly learned or planned information down the chain of command. It was anticipated that more of these would occur between the commanders and the Ops officers, because newly acquired information would help to plan the response, and the plan needs to be passed down the chain of command. Contrary to earlier studies of CBRNE event management (Stojmenovic et al., 2011), the commanders' main function here was to approve the incident action

Table 2. Communication analysis types of utterances, as they emerged from the entire transcript.

Utterance Type	Definition	Example
Acknowledgment	Responses from the listener of a communication, letting the speaker know that (s)he had received the message	Yeah; ok; roger; 10-4
Answer	Responses specific to questions	It was red
Attention Granting	In response to attention requests, letting the speaker know that the listener is paying attention and communication can proceed	Ops (K): Go ahead
Attention Request	Demands for awareness, from speaker to listener, precede a communication	HCo (HOp): Operations officer, this is fire in command
Clarification Granting	Clarifying or rewording a previous communication	Yea, today
Clarification Request	Asking for clarification on a previous communication	Do you mean today?
Complaint	Expressions of discontent	I would never use this. It's not working for me
Explanation	Justifications and reasons for giving a previous communication	Here's why this is important: 'cuz they are going to meet and create an incident action plan
Joke	Intended to amuse, important for alleviating stress in the command post	Fire to police: Do you want to let them know that firefighters are awesome?
Order	Instructions or commands to further action	IC to HCo: So I am gunna need you to call your fire Ops
Question	Requests for information	What colour was it?
Repetition	Forwarding newly learned or planned information down the chain of command	HCo to HOps: The incident action plan has been signed
Statement	Expressions of ideas or facts	That's all I can tell you
Suggestion	Proposals of possible solutions to problems	You might be able to get it by clicking here
Update	Providing the most recent information available	Just to let you know, we just found an IED

plans. This required less updating from the Ops officers because many details were grouped in the action plans. The commanders discussed these action plans and forwarded the documents, again grouping many details, thereby reducing the need for repetitions.

Clarification requests and grants occurred quite infrequently. When an intended listener failed to understand or hear an utterance, such as a question, he would request a clarification. This resulted either in a repetition of the utterance or in rephrasing it. Therefore, clarification grants followed only clarification requests. The number of clarification requests by far exceeded the number of clarification grants, especially in Phase 2, indicative of open-loop communication.

Orders and suggestions were rarely observed. As became clear during the data analysis, the commanders' main role was to communicate to acquire information on proceedings in the hot zone and to approve the incident action plans. They acquired information mainly through questions, answers and updates.

Jokes and complaints were the two least frequent types of utterances in the entire event. However, jokes helped lighten the mood in the command post. Complaints were mainly about PROBE and not related to the event management.

4.2.2. Step 2: utterance sequence analyses

Since communication analysis requires examination of each utterance in isolation to categorize communications by type, this method did not lend itself to identify effective and ineffective communications. To achieve that, sequences of communication belonging together were therefore identified and classified separately. A total of 78.9% of all communication instances (Phase 1: $n = 136$; Phase 2: $n = 133$) were found to be effective. However, six types of ineffective communication were also identified as shown in Table 3. The leftmost column shows the 21.1% ineffective communications (Phase 1: $n = 39$; Phase 2: $n = 33$). The middle two columns show the frequency of each type of ineffective communication in Phases 1 and 2, and the rightmost column shows the total.

Open-Loop Communications occurred most frequently, with more than twice the number of these occurring in Phase 2 than in Phase 1. They comprised unanswered questions, unfilled clarification requests, requests for attention and unacknowledged communication. Some of these may have been miscategorized because non-verbal communications were not recorded, because the video recordings captured mainly the commanders' backs and their interactions with PROBE, making it impossible to capture gestures and facial expressions as well.

PROBE-related issues comprised two types, namely a lack of familiarity with PROBE and software shortcomings/mishaps. The main issue was that not all communications were received via PROBE because the users did not know, or could not recall, how PROBE's communication application worked. All but one of the participants using PROBE had taken a 1-day PROBE training session the day before the event. Apparently, there were too many functions for everyone to recall when using PROBE for the first time. Communication sent via PROBE first went to the IC, who then needed to forward it to everyone else. The IC's scribe had not received PROBE training and did therefore not know of this requirement or how to forward messages. Another problem was that some screens did not populate automatically, need to be refreshed manually. The EMS commander, who did not rely on a scribe, had forgotten this. The Ops officer attempted to communicate with the EMS commander through PROBE, but the messages were not received because of the need to refresh the incident report page manually. Believing that the IC scribe was not forwarding relevant information, the EMS commander searched in vain for information, relying heavily on radio communication for a large part of the event response.

Table 3. Ineffective communications during the CBRNE simulation.

Ineffective communications	Event phase: Phase 1	Phase 2	Total
Open loop	8	18	26
PROBE error	14	3	17
Misunderstanding	4	6	10
Time lag	5	4	9
Key individuals uninformed	4	2	6
Incomplete information	4	0	4

Once the PROBE developer reminded her that the screen had to be refreshed to receive updates, this problem was solved. The EMS commander was then flooded with the previously missed messages. Although most PROBE functions did work as intended, the sending and receiving of attached files, such as the incident action plan, did not. The failure to receive messages sent via PROBE may be explained in two ways. One is that the users did not remember how to send messages correctly; the second could be related to PROBE's network strength. According to the developer, PROBE uses protocols similar to the internet, but in a private and secure intranet connection. Apparently, the wireless intranet connection was weak because the laptops were distributed in the various Ops and command post locations that were further apart than had been anticipated. In addition, the network hardware selected for the prototype ultimately had problems when situated within the vehicles themselves, i.e. the strength of the device was insufficient to penetrate the steel/insulated walls of the vehicles. This problem can be solved with a device capable of sustaining a stronger signal and system tuning. The severity of these problems is addressed in the latent inductive content analysis section.

As Table 3 shows, the remaining types of ineffective communications occurred rather infrequently.

4.3. Latent inductive content analysis results

To assess the severity of the ineffective communications noted above, the latent inductive content analysis focussed on the topic of utterances. It was also divided into two steps: (i) coding each utterance by topic as it emerged from the data and (ii) determining the severity of each.

4.3.1. Step 1: coding

Seven content categories emerged from the transcript are presented in Table 4 with definitions. The leftmost column shows the topic categories; the middle column shows the definition of each topic; and the rightmost column shows an example of each topic. All utterances were coded as one of these utterance topics.

Table 5 shows the number of times a topic was mentioned during the CBRNE simulation. The leftmost column shows the utterance topic. The middle two columns show the frequency with which each topic occurred in Phases 1 and 2. The rightmost column shows the total frequency of topic utterances.

PROBE was the most talked-about topic throughout, accounting for nearly one-half of the utterances (48.9%, as seen in Table 5. It was discussed more frequently in Phase 1 than in Phase 2, mainly because the users were familiarizing themselves with it, sharing their first impressions, concerns and advice on how to use

Table 4. Content of communication definitions found in the entire CBRNE simulation.

Topic	Definition	Example
Action Plan	An utterance was considered to be about the action plan if it had to do with the CBRNE response-planning process	Did you sign the action plan?
Communication	The topic of an utterance was considered communication if it was about talking to or contacting others, unrelated to communication done through PROBE	Did she just say something?
Equipment	If the utterance was about any CBRNE response tool (except PROBE), then it was labelled as equipment	A level B suit would be sufficient, really
Event	If the utterance was about the management of the simulation (unrelated to the CBRNE threat), it was about the event	Lunch will be served on the fly
Offending Agent	If the utterance was about the CBRNE threat, then the topic was offending agent	We've just found an IED
Personnel	If the utterance was about the staff, then the topic was personnel	I need a paramedic in the hot zone
PROBE	If the utterance was about the advanced prototype or an action associated with it, then the topic was PROBE	Scribe: did you get any updates from me there? I tried to send it through there

Table 5. Latent inductive content analysis category totals from the CBRNE event.

	Event phase		
Topic	Phase 1	Phase 2	Total
PROBE	487	316	803
Action plan	107	161	268
Personnel	92	68	160
Event	47	95	142
Equipment	53	62	115
Communication	25	54	79
Offending agent	58	17	75
Total	869	773	1642

PROBE. The popularity of PROBE suggests that the command post-team members were not as preoccupied with the CBRNE mission as had been observed in two previous simulations. We had therefore expected that discussion would focus on the action plan, equipment and other response-related issues. As such, PROBE communications were only of marginal importance to the event outcome. The hazmat commander even chose to forgo a situation status update to learn more about PROBE instead. A situation status update is a meeting between the Ops officers and the commanders in which everyone reports their team's progress. Another reason for this prominence of PROBE-related utterances was that the Ops officers did most of the planning, leaving only the approval of the incident action plans to the commanders, giving the commanders more time to explore PROBE. Because the commanders also relied heavily on PROBE for communication, it was talked about with regards to obtaining information from the Ops officers and forwarding messages down the chain of command. Occasionally, this led to ineffective communication, the severity of which is discussed later in this section.

Planning the CBRNE event management was the second most frequently observed topic, followed by *personnel*, *event*, *equipment*, *communication* and *the offending agent(s)*. Although the command post-team makes crucial strategic decisions necessary to manage the event, making planning and revising the action plan their primary purpose, these accounted only for 16.3% of all communications. The action plan was discussed more often in Phase 2 in the second action plan because the commanders changed the level of PPE suits as the Ops officers suggested, whereas the first action plan was not altered. However, the role of the Ops officers in managing the first responders in the hot zone, such as deploying of equipment and creating the incident action plan, reduced most of the need for planning in the command post as evidenced by the figures in Table 5. Discussions about the personnels participating in the simulation occurred more frequently in Phase 1 in which commanders were getting acquainted with everyone's teams and clarifying who would be among the first entry team's members. In Phase 2 where everyone knew who was part of the response team, personnel-related discussions became less frequent. Event management discussions, such as communication about lunch, doubled in Phase 2 when it was time for lunch and coffee breaks. Discussions about equipment other than PROBE remained relatively constant. In Phase 1, the commanders decided on everyone's radio frequency and, in Phase 2, discussion concerned the PPE needed for re-entry to the hot zone. Conversations with other members doubled in Phase 2, as commanders talked about sharing information down the chain of command and asked about other communications more often. Communication about the offending agents was minimal in Phase 2 as they had already been neutralized and deactivated in Phase 1. The finding that the event management was discussed more frequently than equipment or personnel suggests that the Ops officers were experienced requiring little or no input from the senior officers.

4.3.2. Step 2: assessing the severity of ineffective communication

The severity of ineffective communications was assessed by examining the topic of each such instance as well as the types and topics of utterances immediately following the ineffective communication, to identify the consequences of these. This level of analysis is not included in the content analysis literature, but it was necessary to understand the severity of ineffective communications.

In total, 23.6% ($n = 17$) of all ineffective communications were PROBE related. However, only one of these resulted in a communication breakdown. Others were averted because the commanders used their radios as backup when information was not coming in through PROBE. Right from the start of the simulation, they requested confirmation of all communications, to ensure that messages were received by the intended listener(s).

The single communication breakdown that had a severe consequence occurred in Phase 2. It involved the hazmat first responder and the explosive disposal unit (EDU) officer in the hot zone who was running out of oxygen. Both were dressed in high-level PPE, which are air-tight safety suits for highly dangerous situations. This suit is sealed onto the responder's body, with oxygen delivered via a tank carried on the back inside the suit. The oxygen lasts for 1 h, but could be as short as 30–35 min depending on the wearer's level of exertion. The hazmat commander received a somewhat alarming radio update from his Ops officer. The IC overheard this and requested clarification from the hazmat commander, who explained that the two responders had most likely already lost their air supply. Apparently, the chemicals had already been neutralized and the EDU and hazmat first responder were in the hot zone, waiting for forensics responders to enter. The EDU officer's radio signal was too weak to enable him communicating with his team, relying instead on the hazmat first responder, who was with him in the hot zone, for relaying communication. Meanwhile, the police forensics officers were waiting for the commanders' approval of the second incident plan before entering the hot zone. However, the Ops officers' proposed action plan had not yet reached the commanders since PROBE was not forwarding attachments. Therefore, the document had to be written and physically brought to the commanders. It took the commanders, who were unaware of the event unfolding in the hot zone, another 6 min to approve the incident action plan, and the entry was to take place ∼10 min after that. However, because the commanders were then told that only a negligible amount of radiation had been detected, the responders now needed to wear a lower level of PPE. This change delayed the response team so that the forensics team finally made entry 2 min later than the original 10 min planned after the second action plan had been approved. This timeline is shown in Fig. 4. The moment the IC was notified that the forensics had entered the hot zone, the hazmat commander was informed that the EDU and hazmat officer were running out of air in their air-tight PPE. Apparently, the EDU officer had gone to the decontamination area, but no one was there so he had actually run out of oxygen, collapsing to the ground. Thankfully, nearby hazmat first responders discovered him and removed his suit. This chain of events was surprising as the EMS commander had ordered a paramedic to get suited up in PPE and stand-by the hot zone, 3 min before the second incident action plan was approved. This should have given the paramedic enough time to get ready and be in a position by the decontamination area. The reason for the lack of his immediate presence and assistance is unknown. Other than that unfortunate incident, 'the exercise went excellent[ly]', according to the police Ops officer.

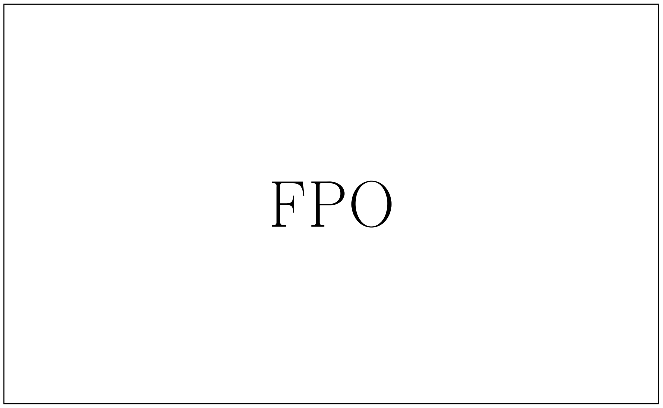

Figure 4. Timeline of the event in which a responder ran out of oxygen.

4.4. Inter-rater reliability

Cohen's kappa (Cohen, 1960) is widely used in behaviour-coding research (Bakeman, 2000); (Burla et al., 2008) as well as being relatively simple to compute (Lombard et al., 2010). Conceptually, it is equal to the observed proportion of agreement between raters, after adjusting for the proportion of agreement expected by chance (randomly). An obtained value <0.41 represents a weak inter-rater reliability; a value between 0.41 and 0.60 is considered 'moderate' (Burla et al., 2008), and a value between 0.60 and 0.80 is deemed 'satisfactory'. A value >0.80 is almost 'perfect'. The inter-rater reliability was calculated separately for the two analysis types. For communication analysis, agreement between the two researchers was 70.2%, yielding a moderate value of 0.5903 by Cohen's kappa. The main discrepancy was due to the second researcher misclassifying questions and answers as well as clarifications requested or granted. For latent inductive content analysis, agreement was 62.9%, yielding a value of 0.5532 by Cohen's kappa, also considered moderate. The main issue here was that the second researcher was largely unfamiliar with the context or the concept of PROBE, so she labelled many 'PROBE' communications as 'equipment'. In both cases, the disagreements were settled by negotiation.

4.5. Communication and teamwork

As a thorough social network analysis is reported in detail elsewhere (Stojmenovic and Lindgaard, in press), only a summary of the speaker-related findings is provided here. The hazmat commander spoke most frequently, closely followed by the IC and the EMS commander. One would have expected that the IC should speak most frequently of all because he is in charge of the entire event. However, as the hazmat commander was older than the IC, he may also have had more experience in the command post. At the beginning of the event, the IC informed the other commanders that their advice was welcome. Later, he commented that he missed being involved hands-on with the response, saying that he found that 'when you move on, you start to miss the things you used to do', motioning towards the hot zone as he spoke. It is thus possible that a difference in experience may explain the apparent reversal of speech frequency between the two officers. In addition, even though a bomb was involved in the event, the IC who was from the police department did not communicate more because he was only notified about it when it had just been found, and when it was deactivated. His advice on how to handle it was therefore not needed. Although the IC is in charge of the event, and therefore is responsible for making the biggest decisions, in the present case, it was unclear whether he changed the incident action plan before approving it, which was the biggest decision to be made. Since the researchers did not have access to that file, it can only be speculated that the IC had more input when approving it, and his input was not discussed.

The EMS commander spoke the least of the three commanders. It is possible that this may be attributed to the fact that there were only three 'casualties', presented in the form of pie plates with symptoms written on them. The 'patients' therefore did not require attention. The EMS first responders' duties were limited to monitor the vital signs of teammates entering and exiting the hot zone—a routine task for paramedics, not requiring a lot of communication.

Taken altogether, of the 21.1% of all communications being ineffective, only one led to an actual communication breakdown. The content and context of the utterances of ineffective communications showed that 63.4% of all such instances occurred between commanders and Ops officers, mainly due to misunderstandings with PROBE. The remainder occurred among commanders, scribes, the PROBE developer and the event mangers. Only

11.1% of ineffective communications occurred between commanders, suggesting that communication among commanders was highly efficient and effective. This is probably because the commanders were collocated and could hear each other's radios, leaving little room for confusion. The common goals of neutralizing the chemical, deactivating the bomb, treating patients and collecting evidence were all completed in a timely fashion. The one communication breakdown was not an intended part of the simulation scenario. However, the high frequency of effective communication, coupled with the ability efficiently to overcome breakdowns when they did occur, suggests that the overall teamwork among the group of commanders and Ops officers was effective and successful.

4.6. CBRNE simulation goals voiced during debriefing

During the debriefing session, it became clear that the agencies had different agendae and goal with the simulation. The fire and hazmat personnel's goal was to expose the responders to hands-on CBRNE training. For example, in the process of approving the second incident action plan for re-entry into the hot zone, the IC asked the hazmat commander 'Why would they have to go back in?' The hazmat commander replied, 'I think it's just for the practice... I think they're just getting guys into suits'. In addition, the hazmat team and the police team members wanted to practice working with the other two agencies. The police personnel and many of the others were from other cities in New Brunswick, as well as representing different agencies and different levels of government. Collectively, the police officers' goal was primarily to get practice coordinating with other sectors and agencies. The EMS goals were to test the usability of a new worksheet and to test PROBE. The EMS team had recently become a provincial team such that, in case of a larger CBRNE-related event, any paramedic, anywhere in the province could be dispatched to the scene. Therefore, some procedures for large-scale events were being changed, requiring new forms for the paramedics to support their tasks. As most of the participating personnel had taken part in the PROBE training session the previous day, they focused on testing it during the simulation, which explains why they relied so heavily on PROBE for communication and used it throughout the event as noted earlier. Representatives of the media had been invited to the simulation, which tended to lend it quite a different atmosphere than had been observed in previous simulations, all of which had been closed to the press. Reporters, cameras and photographers were everywhere recording the command post, and interviewing event coordinators at the beginning of Phase 1. The commanders may thus have acted more casually than they typically would, which may account for the jokes and socialization that occurred in the command post.

5. DISCUSSION

5.1. Theoretical implications

Distributed cognition guided the data collection and analysis in this paper. It enabled the researchers to examine the interactions and exchanges of information between commanders, and between commanders and PROBE. It also helped the researchers to untangle and understand the serious communication breakdown observed. Since this incident was partially the result of the Ops officers' interactions with PROBE, it testifies to the importance of the framework focusing on both human–human and human–computer interactions. The observation that the IC had to clear the messages before passing them onto the various teams was a responder-specific procedural issue that had not been observed in our previous CBRNE-related research. Once PROBE is able to handle messages in the way intended, this will no longer cause problems. The need manually to refresh the screen will also, to the best of our knowledge, be rectified.

5.2. The role of PROBE

The PROBE prototype was intended to aid communication, supplement decision making and facilitate effective teamwork. Some issues did arise as a result of shortcomings due to the fact that PROBE was still a prototype rather than a fully fledged management decision-support system. Other issues arose from the fact that the responders had only received a minimum of training on the software the day prior to the simulation. Thus, they had no additional practical experience using PROBE. In the command post, more time was given to testing PROBE than to managing the event, leaving little necessity for teamwork and decision making. PROBE did supply a summary of events inputted into it, to aid in writing the incident report, a summary of the event response and outcome by CBRNE responders. With a fully operational version of PROBE, responders will be able to continue communication even when their radios may not be working. It will also help to create detailed incident reports as team members representing each agency must delivers upon completion of the CBRNE event or simulation. Access to a wide range of CBRNE information sources necessary for the successful event management should also prove an advantage for emergency response teams.

5.3. Modification of analysis methods

At one level, communication analysis and latent inductive content analysis were adequate for this research. Communication analysis facilitated understanding of how information was being shared. However, at another level, the method as described in the literature did not entirely meet the analytic requirements. Sequences of communications had to be analysed to identify instances of effective and ineffective communications in the CBRNE transcript. This added step provided local context enabling the researchers to see clearly which utterances demanded a response, and when responses did/did not occur. We argue that examination of sequences is essential when interpreting data intended to yield an understanding of communication effectiveness in instances in which effectiveness is determined by open- and closed-loop communication. Latent inductive content analysis was used to categorize the topic of each utterance to determine the severity of ineffective communications. This too required an additional step to the way the method is described in the literature. The original analysis involved the coding of all utterances by topic, and the examination of the utterance topic(s) involved in the ineffective communication. The additional step involved examination of types and topics of utterances immediately following the instances of ineffective communication. This was necessary to reveal the consequences of such communications as well as to determine the severity of ineffective communications.

Taken together, these additional steps, the two analysis methods helped the researchers to gain a deeper understanding of communication in the command post during the CBRNE simulation. Although it is acknowledged that these additional steps may not always be necessary, it would be helpful for future researchers to refine the descriptions of these two analysis methods in the literature by including them. The next step towards such refinement would thus be to identify the circumstances under which such additional scrutiny of data is required.

One interesting issue concerns the separation of communication and content analyses. Communication analysis as described by (Kramer, 2009) included both the type and the topic of utterance, whereas, following some research published in the literature (Hazlehurst et al., 2007), these were kept separate in this research. However, to gain a better understanding of communication, it was important to analyse the type and topic for each utterance simultaneously. Keeping communication and content analyses separate was thus not necessary. It is therefore suggested that the method applied by (Kramer, 2009) be used.

With respect to the somewhat modest inter-rater reliability ratings, it would have been helpful if the primary researcher had explained the category definitions in more detail and allowed the second researcher to ask questions of clarification at the outset. It also suggests that the category definitions may have been insufficiently clear to allow the second rater to categorize 10% of the transcript correctly.

6. CONCLUDING REMARKS

Although all but one participant had received training a day before the simulation, they had forgotten some of PROBE's features. One way this could be prevented in a future simulation would be to provide responders a quick review of the software capabilities immediately before the simulation, to remind them that PROBE could not send all types of attachments. In addition, a pocket-size cheat sheet would have been beneficial for the participants using PROBE. These may have prevented, or at least reduced, the consequences of the unfortunate mishap. Some types of alarm should be incorporated into the PPE to signal oxygen levels to the responders wearing them as well as to the personnel taking care of the wearer.

Because some of the details concerning the simulation reported here were revealed only in the briefing at the end of the simulation, it would be helpful for researchers to know more about the management structure, the scenario, the magnitude of the event and the number of professionals expected to take part in it ahead of time. That information was not available to us in this simulation. Because of this, the checklist shown in Appendix was devised to help future researchers plan and organize field data collection strategies when observing multi-agency emergency responses.

CBRNE training simulations are very expensive and time-consuming and are therefore not run very often. Few are open to researchers. The opportunity to observe and study such simulations is valuable as these add to researchers' understanding of the CBRNE response as well as enabling them to test data collection and data analysis methods under real-life circumstances. These opportunities also add our understanding of some of the challenges associated with conducting field studies of software prototypes. The attached checklist is intended to help researchers better to prepare for observing CBRNE emergency response personnel in the future.

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APPENDIX

Emergency services responders deal with several types of emergencies as part of their normal, daily routines (Kuban et al., 2001). For example, the discovery of an unattended brown parcel left at an airport may lead to its immediate closure; departures are postponed until further notice, arrivals are rerouted, people are evacuated and luggage service is halted, all of which are both time-consuming and very costly (Stojmenovic et al., 2011).