UNDERSTANDING TEAMWORK AND COMMUNICATION IN A CHEMICAL, BIOLOGICAL, RADIOLOGICAL, NUCLEAR, AND EXPLOSIVES MANAGEMENT DECISION ENVIRONMENT

by

Milica Stojmenović

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Abstract

The purpose of this thesis was to acquire an understanding of teamwork and communication amongst CBRNE event management personnel, using a management decision support system advanced prototype. Such a support system does not exist in Canada yet. From an analysis of sequences of utterance-types, communication analysis revealed mostly effective communications (78.9%), with some instances of ineffective communication. To understand the possible consequences of these, the utterance topics and utterances immediately following an ineffective communication, a content analysis was performed to reveal the severity of each of these. In fact, only one was severe. Thus, nearly all of the ineffective communications were of little or no consequence to the effectiveness of the simulation management. In order to help future researchers improve their preparations for observing CBRNE field studies and hence optimize their data collection strategies, a checklist was generated from the valuable learning experience that this simulation offered.

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Understanding teamwork and communication in a Chemical, Biological, Radiological, Nuclear, and Explosives management decision environment

Milica Stojmenović

Introduction

Emergency services responders deal with different kinds of emergencies as part of their normal, daily routines (Kuban, MacKenzie-Carey, & Gagnon, 2001). Disastrous mass casualty emergencies such as Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) events are typically very complex and occur rather infrequently. In the period 1873-2003, there were two airplane bombings, four letter bombs, and 170 bombs, all CBRNE events in Canada alone (Leman-Langlois & Brodeur, 2005). A classic example is an unattended brown package left at an airport. Once such a package is discovered, it is considered a threat. The airport is closed, departures are postponed until further notice, arrivals are rerouted, people are evacuated, and the airline industry is loosing money by the minute. The contents of the package can be anything, and this unpredictability and possible consequences make it very hard and stressful to manage such an event. CBRNE event management is highly complex because it includes, and goes beyond, crisis management in search and rescue situations, emergency medical events, hazard mitigation, providing temporary shelter and feeding, and restoring basic services (Waugh & Streib, 2006). Many professionals representing different agencies and disciplinary backgrounds such as police, fire department, and Emergency Medical Services (EMS) are involved in responding to CBRNE calls (Simpson & Hancock, 2009). They need to work closely together as a team in order successfully to manage a timely response to an event that could potentially be, or escalate to become, very large.

Not surprisingly, 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 at once. Everyone in the command post is receiving information from different sources and technologies. For example, respective responder teams are updating via radio from the field; members of the command post are coordinating resources with dispatch via the phone, and communicating with the event manager in face to face interactions. This variety of communication modes and technologies can lead to misunderstandings and incorrect actions, some of which could potentially be fatal for the outcome of the event.

In order to gain an understanding of teamwork and communication in a CBRNE event, the management of a CBRNE event is described next. It is followed by a description of the responsibilities of the participating agencies (EMS, fire, and police) to highlight the procedure of a CBRNE response. Next, an explanation of the structure and importance of team management is provided, which describes the chain of command communication. Thereafter, a brief outline is given of the larger project on which this thesis based. The theoretical background driving this research is then discussed. Next, the concept of teamwork is discussed in order to define it and the role it plays in the command post. Subsequently, the concept of communication is explained and operationalized. The introduction ends with a discussion of the analysis methods chosen for this thesis. This is followed by the method, results, discussion, and conclusion sections.

The Management of a CBRNE Event

Many CBRNE response procedures have been developed (Federal Emergency Management Agency, 2005; Jederberg, Still, & Briggs, 2002) in an effort to manage each event, as these are unique and require flexibility in the response procedure (Humphrey & Adams, 2011). CBRNE events are also unique because each differs in extent of possible damage, type of offending agent, and response requirements (Humphrey & Adams, 2011). The organization of such large events that potentially involve mass casualties, is quite different from an emergency in a hospital, for example. When a badly injured, barely conscious, patient in extreme pain is admitted to a hospital, a standard protocol is followed in which the doctor on duty examines him, proposes a diagnosis and either administers treatment or forwards the patient to a specialist, the operating theatre, the Intensive Care Unit, or a ward for further treatment (Canadian Institute for Health Information, 2005). The patient would be seen by doctors and nurses, all from a common medical background, and all in the same location. By contrast, each CBRNE event is unique and typically unpredictable, with threats rarely occurring in the same location more than once. The example of the patient in a hospital environment typically involves considerably less personnel than in a CBRNE event, where the complete response can involve hundreds of responders (Humphrey & Adams, 2011). In order to manage these threats of unknown magnitude effectively, specially CBRNE-trained representatives from the different agencies (police, fire, EMS, possibly public health, and others) coordinate their actions with each other (Van der Kleij, de Jong, te Brake, & de Greef, 2009). These experts come from different disciplinary backgrounds, with different responsibilities, terminologies and protocols (Humphrey & Adams, 2011).

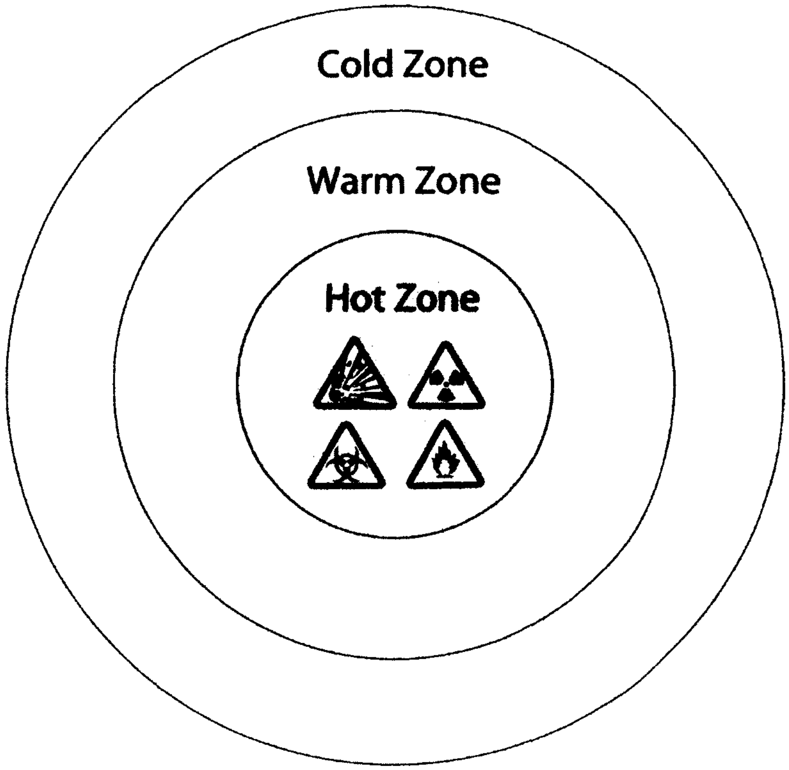

Figure 1. Danger zones in a CBRNE event

One of the first requirements in a CBRNE event is to divide the area around the threat into three different levels of safety zones, as shown in Figure 1. The hot zone is the area with the offending object or agent that is directly affected (May, 2009; Humphrey & Adams, 2011). If responders are unsure of what is going on in the hot zone, they might send in a robot (seen in Figure 2, from Atomic, 2011) to scan the area and acquire a 3-D map of the hot zone, which is enhanced with CBRNE measurements (such as radiation levels and air quality and temperature) before the first responders are sent in (Atomic, 2011). First responders are then situated in the hot zone, attempting to render the object safe and perform triage on any casualties. The warm zone is the area around the hot zone that is not in immediate danger (Humphrey & Adams, 2011), where the decontamination tent is set up. In larger events, the first line of officers called Operations (Ops) officers set up post in the warm zone to manage the first responders in the hot zone.

Further away is the cold zone, a safe area where the command post may be set up unless it is even further removed from the scene. From there, the commanders manage the entire event.

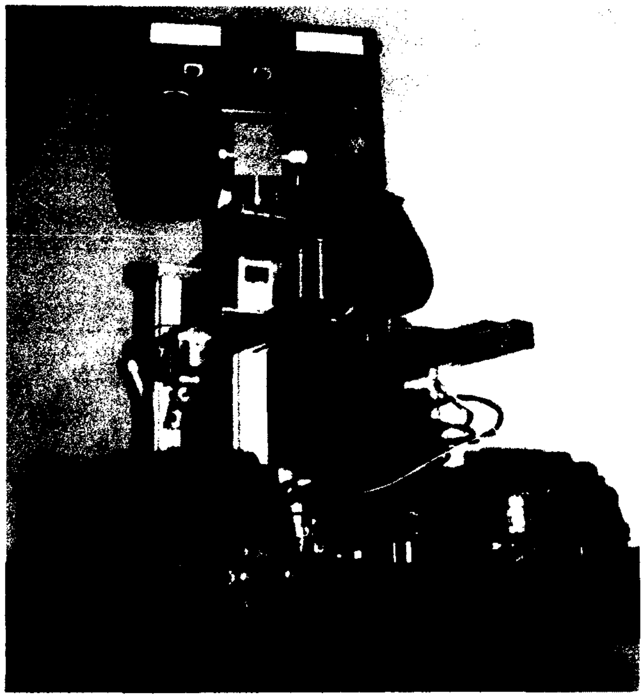

Figure 2. CBRNE detection and hot zone mapping robot (borrowed from Atomic, 2011)

Much intensive training is essential for CBRNE first responder teams to optimize their response. This happens via simulation-based training (Salas, Rosen, Held, & Weissmuller, 2009). Simulation-based training provides structured learning experiences that attempt to simulate real CBRNE events. This kind of training ranges from table-top exercises to field simulations. Table-top exercises usually involve fewer than 15 people who, sitting around a table, are given a scenario and asked to discuss how they would respond in the hypothetical situation. These exercises are a good way to practice responses to possible situations, according to Salas et al. (2009). Fully-fledged scenario-driven field simulations may involve hundreds of people, including entire response teams as well as hired actors pretending to be casualties in the event. The emergency response teams typically include Emergency Medical Services (EMS), police and their teams, and fire fighters and their specialized team of hazardous material technicians (hazmat). Each of these teams has different responsibilities in a CBRNE event. Therefore, the responsibilities of each of these agencies are outlined in the next section.

Emergency Response Team Responsibilities

This section outlines specific goals and responsibilities of each agency involved in managing a CBRNE event. All responders receive domain-specific training in addition to CBRNE training. The EMS team first takes the vital signs, known as pre-vitals, of anyone on the CBRNE response team who is about to enter the hot zone. Vital signs usually include heart rate, blood pressure, body temperature and respiratory rate. Pre-vitals provide a baseline measure of the first responder's condition, enabling a comparison with their post-vitals, the vital signs taken when they exit from the hot zone, to ensure they have not been unduly affected or injured while in the hot zone. Once the pre-vitals are completed, the EMS first responders' goal is to perform triage and remove casualties from the hot zone while assessing the severity of injuries and reporting these to the EMS Ops officer who shares this information with the EMS commander. Knowledge of the nature and extent of injuries is important for assisting in the identification of the offending agent; this information is then used to determine how to decontaminate people. As soon as the firefighters have decontaminated the casualties, the EMS team forwards them to nearby hospitals for treatment and discharges those who were not injured or whose injuries do not warrant further treatment. One member of the EMS responder team keeps track of the time that each responder has spent in the hot zone to ensure that no one is in there longer than safety permits. When a responder emerges from the hot zone right after they have been decontaminated, another EMS first responder takes their post-vitals, and treats any injuries the person may have suffered (May, 2009).

The police team consists of bomb technicians, the Forensic Identification Section (also referred to as FIS and Ident), and generalists. The bomb technicians are included in the CBRNE event response when there is a possibility that explosives are involved. They undergo specialized training and their job is to disable the bomb to prevent it from detonating. The Identification officers are responsible for collecting and cataloguing evidence from the scene in order to document any proof, should the event go to court in the future (Reutter et al., 2010). The time lapse between an event and the ensuing court case can be several years, which emphasizes the need for accurate and detailed records of all evidence from the scene of the event as well as an ability to track each item of evidence. Generalists help organize the refuge of hostages and victims, seal off the three zones, and help keep public order by, for example, redirecting traffic around the sealed-off area.

The hazardous materials (hazmat) team is a specialized team of firefighters with several levels of specialized training that differs from that of the bomb technicians and other CBRNE and crisis management training. They take charge of the fire department responders during a CBRNE event. This group primarily deals with sampling and testing harmful chemical agents, to identify and neutralize them. In the warm zone, there are specialized hazmat trucks (seen in Figure 3) in which hazmat experts have access to a multitude of databases to identify the offending agent(s), monitor weather conditions, remotely monitor the thermal camera activity in the hot zone, etc. The inside of such a truck looks like a sophisticated lab, equipped with numerous computer systems, whiteboards, papers, handbooks, and other CBRNE equipment. The hazmat team controls the entry into and exit from the hot zone. They are also 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 identification officers have acquired all the necessary evidence from the hot zone, the hazmat responder team's final job is to decontaminate and clean the area.

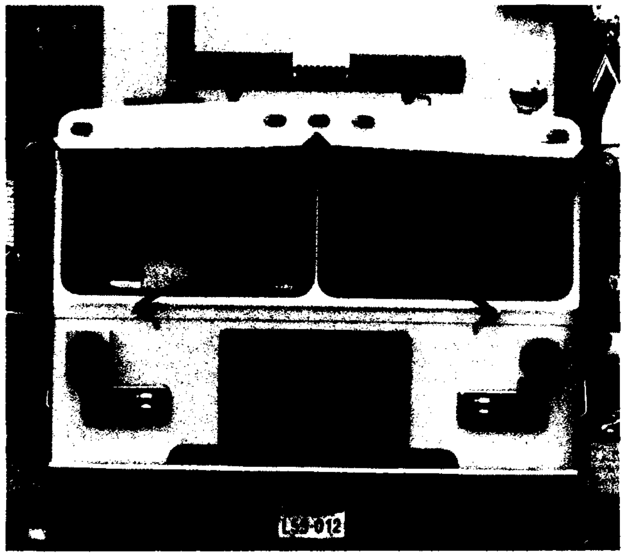

Figure 3. The hazmat heavy rescue response truck

The coordination of these agencies is the key to a successful emergency response, which is the responsibility of the commanders in the command post. Each agency and every commander eventually produces a full report of the event to their own agency. In addition to understanding the various response team responsibilities, it is important also to outline the structure of the response to gain further understanding of the CBRNE event management. This is done in the next section.

The Structure of Team Management

The CBRNE event response team is composed of a chain of command of responders, with different responsibilities (Humphrey & Adams, 2011). The structure of each event varies as a function of its size and complexity (Owen, Douglas, & Hickey, 2008). According to the Emergency Management Ontario Ministry of Community Safety and Correctional Services (EMOMCSCS), at most, there are three levels of operational response, depending on the severity of the emergency and the appropriate number of personnel required to respond. (EMOMCSCS, 2008). According to May (2009), and as shown in Figure 4 below, first responders deal with the dangerous situation in the hot zone in a hands-on manner. These first responders include paramedics from EMS, generalists, bomb technicians if explosives are suspected or known to be involved, identification and forensic officers from the police department, and firefighters and hazmat officers from the fire department (Van der Kleij et al., 2009). In larger events, first responders report to their Ops officers who, in turn, report to their commanders.

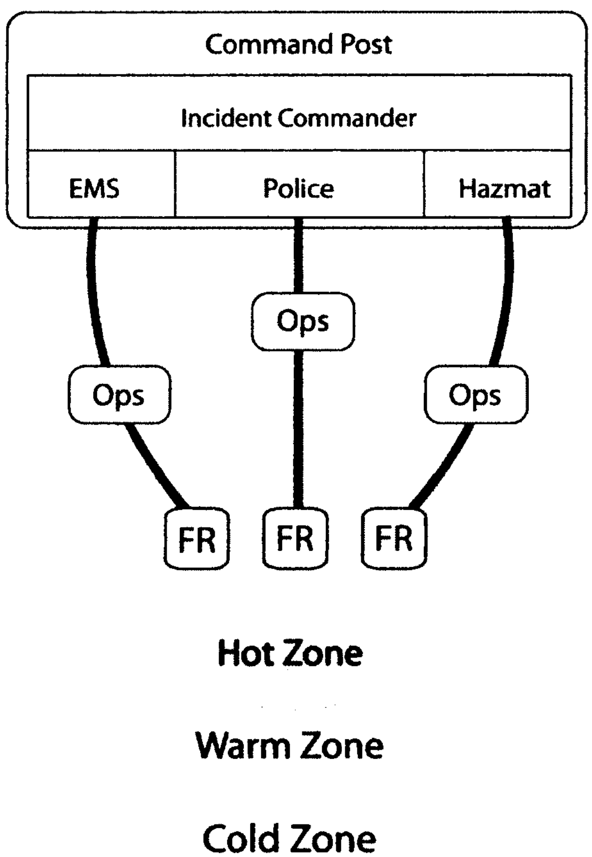

Figure 4. Response Structure and Positioning in the Zones (FR = First Responders)

In a large event, each of the three agencies has a different designated area in the warm zone, in which the Ops officers set up their posts. Ops officers from each agency work together to create and implement an Immediate Incident Action Plan (EMOMCSCS, 2008; 2009), which is a short-term to-do list. Ops officers manage the first responders in the hot zone, the deployed equipment, and they are responsible for keeping the commanders in the command post up-to-date (EMOMCSCS, 2008; 2009). In fact, if the event is complex enough to require Ops officers, the on-scene first responders only communicate with their Ops officers, who relay relevant and important information to their commanders in the command post (EMOMCSCS, 2008; 2009; May, 2009). However, if the event is judged as being reasonably small and not overly complex, the members of the command post take on the Ops officers' responsibilities, leaving out that layer of response. The simulation on which the present research was based included an Ops layer.

In any CBRNE event, there will always be a command post in the cold zone or even further away from the scene, but always well removed from the hot zone for the safety of the commanders and because they are often in contact with additional agencies (e.g. Health Canada, Public Safety Canada). The command post team's objectives are to coordinate the emergency response so that it preserves life, maximizes safety, and diminishes threat while trying to protect the affected property, minimize cross contamination, and preserve and collect evidence (May, 2009). Commanders approve the Immediate Incident Action Plan (EMOMCSCS, 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. Commanders are also in charge of identifying and resolving response issues (e.g. the lack of equipment on site), providing advice to responders, and implementing the emergency response plan (EMOMCSCS, 2008; 2009). There are usually at least three commanders, one for each of the police, fire, and EMS agencies. Commanders also determine the level of Personal Protective Equipment (PPE) to be worn in the hot zone as well as PPE that casualties need to wear once they have been decontaminated. In a smaller event, the Ops officers' responsibilities are merged with those of the commanders and taken on by the management team in the command post.

The Incident Commander (IC) is in charge of coordinating all responders, including the command post (Moynihan, 2009; Simpson & Hancock, 2009). The IC communicates and gives orders to all the commanders and Ops officers. In addition, he or she can veto the Immediate Incident Action Plan and in some cases, their approval might be necessary (Jederberg, Still, & Briggs, 2002). If the action plan is vetoed, the IC is responsible for providing alternatives (Jederberg et al., 2002). Ideally, the IC would be 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.

During a CBRNE event, the command post team is considered the most important group because it makes the crucial strategic decisions necessary to manage the event. For that reason, commanders were the unit of analysis in this thesis. One major issue is the need to share information updates timely and effectively among all responders, including the commanders, to avoid misunderstandings. This thesis is an extension on previous work, in which an advanced prototype of a CBRNE management decision support system was under development (Lindgaard, Dudek, Noonan, Sen, & Tsuji, 2009). In order to learn more about how technology may be applied to support or improve human-human interaction and human-artefact interaction in the context of managing a CBRNE event, it is necessary to analyze teamwork and communication among the CBRNE management team. Thus, the objective of the research in this thesis was to determine the degree to which a CBRNE management support system may supplement existing technologies and help to optimize event management. In an effort to provide meaningful context, the prototype is discussed in the next section.

Outline of the Advanced Management Decision Support System Prototype

The CBRNE exercise described in this thesis is a continuation of a project sponsored by CBRNE Research and Technology Initiative (CRTI; # CRTI-06-0317TD) called PROBE and carried out in partnership with a large team of people representing a wide variety of organizations. These include the Royal Canadian Mounted Police – Canadian Bomb Data Centre, National Research Council – Canadian Police Research Centre, Department of National Defence – Defence R&D Canada & Director General Nuclear Safety, Carleton University – HOTLab, Loraday Environmental Products Ltd., International Safety Research Inc., Responder teams from 11 major Canadian Centres, and the AMITA Corporation (Amita, 2008).

PROBE is a CBRNE management decision support system software. The purpose of PROBE is to aid interoperability between response agencies by recording, storing, and sharing CBRNE event information (Amita, 2008). Commanders and other responders managing the event, such as the Operations officers, will use PROBE. PROBE provides responders with CBRNE databases, standardized forms, automated evidence collection by RFID, information on patient triage, and allows responders to monitor the CBRNE event progression (Amita, 2008). PROBE provides responders with these functions via a suite of CBRNE event management software applications. One application available on PROBE is the Chemical Biological Response Aid (CoBRA) which is a large chemical database, including a software called PALM Emergency Action for Chemical- WMD (PEAC-WMD) which stores information on chemicals that helps identify and render CBRNE materials safe (Amita, 2008). Socius is another application that will be linked to PROBE. It is a database in which RCMP bomb technicians enter and store records of incidents involving explosive devices (Amita, 2008). The last application is the Rapid Triage Management Workbench (RTMW) which supports the medical management of casualties

(Lindgaard et al., 2006). PROBE will also be capable of supplementing real-time communication across agencies (Amita, 2008). This is especially important for the response 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 in the command post and with responders is predominantly face-to-face and via radio (Humphrey & Adams, 2011). PROBE will not replace the radios. Rather, it records and integrates communications and information during a CBRNE event, which also helps produce an incident report after the event. In an environment where advanced technology is limited (e.g. contaminant detection technology and radios; Humphrey & Adams, 2011), these applications are all intended to support CBRNE event management by helping with the coordination and planning of response efforts and help with the distribution of information (Amita, 2008). Since the research in this thesis is an extension of previous work with PROBE, the next section outlines the differences between the previous CBRNE simulation and the CBRNE simulation used in the current research.

Comparing the Present and Previous Events

The previous work included a half-day simulated event staged at a famous sports center in central Toronto, Canada in April 2009 (Lindgaard et al., 2009). It was run with a different scenario and different personnel than in the present research. Participants in the previous study had access to an earlier version of PROBE. The original intention was to test PROBE and connect to Ottawa via satellite, as part of the test. However, the very poor weather conditions made it impossible to link up via satellite: PROBE was not able to perform well in the very heavy wind, rain and cold weather. As the Toronto responders unexpectedly also had to respond to three actual CBRNE calls fairly early on in the simulation, they lost many of their personnel. For those reasons, the remaining responders resorted to relying on their conventional paper forms to do their job; PROBE was not used at all. Therefore, researchers observed the actions of the CBRNE responders and drew conclusions concerning what such a management support system should deliver, without testing it (Lindgaard et al., 2009). New Brunswick commanders and Ops officers in the CBRNE simulation observed for this thesis had access to laptops with the advanced prototype of PROBE running and used it throughout the exercise. This thesis focuses on the influence PROBE had on teamwork and communication.

There were many other differences between the past and present studies as well. For example, in the previous event, there was no Ops layer and commanders communicated directly with the first responders in the hot zone. All communication between first responders and the command post took place via radio and face-to-face conversations throughout the entire event. This was not the case in the present study, as the commanders only communicated with the Ops officers, who forwarded information to the commanders from the first responders, following the chain of command. In fact, there was a radio in the command post in the present study that allowed the commanders to listen to the communications between first responders and Ops officers. However, the IC mentioned that the radios should be filtered preventing those communications from bothering the members of the command post. Another distinction between the past and present CBRNE event simulations is the terminology describing some of the personnel. While the commanders were referred to as such in the present study, they were referred to as 'team leaders' in the earlier study. A further distinction between the two events is the chain of communication of the hazmat experts in the specialized hazmat fire trucks shown in Figure 3 (p. 8). In the previous event, the hazmat experts in the hazmat truck had no direct contact with the first responders, only with the team leader in the command post. Their task was to use the information passed on by the hazmat team leader to search the many various databases. They communicated only via radio with the hazmat team leader who passed on relevant information to the first responders to help them identify and neutralize the offending agent as quickly as possible. In the current event, these hazmat experts were the Ops officers, who were in direct contact with both the commanders and the first responders.

Several theoretical frameworks were considered for guiding the research in this thesis. In order to get a better understanding of teamwork and communication in a CBRNE command post, team situation awareness (TSA), grounded theory, and distributed cognition were examined as possible theoretical frameworks. The identification of a suitable theoretical framework is discussed in the next section.

Identifying a Suitable Theoretical Framework

This thesis assessed teamwork and communication in a CBRNE command post. The research was qualitative, based on in situ observation. A suitable theoretical framework had to allow researchers to examine the interaction amongst the CBRNE commanders, and the interaction between the commanders and PROBE. In order to select the most suitable theoretical framework, three possible candidates were considered. Team situation awareness was first considered, then grounded theory, and finally, distributed cognition. Situation awareness is "the perception of environmental elements within a specific time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). Individual situation awareness is extremely important because it helps to generate team situation awareness, which focuses on the entire team. TSA is the degree to which each team member possesses and maintains knowledge required for their job, for their team mates and their team tasks (Gorman, Cooke & Winner, 2006). Team situation awareness analysis covers team work everywhere, from air traffic control to surgical teams in operating theatres and hospital emergency systems (Autrey & Moss, 2006). However, team situation awareness does not account for the use of artefacts, and thus does not allow for the examination of the interaction between people and artefacts (i.e. PROBE). It was thus not considered suitable for identifying communication breakdowns in the management of a CBRNE event, which is the goal of this thesis.

Grounded theory comprises a set of procedures that should be followed to uncover the interaction between people and changing environments, which will help researchers develop concepts that describe and explain the specific topic under study (Corbin & Strauss, 1990). The purpose of grounded theory is to build theory while maintaining the connection to the original data – much more than simply deriving meaning from data (Furniss, 2008). Building theory was not the objective in this thesis. Grounded theory also does not account for interactions between humans and artefacts, and thus does not enable the study of the interaction between the commanders in the CBRNE command post and PROBE. Of the possible theoretical framework candidates considered to examine teamwork and communication in a CBRNE command post where a software prototype was being used, this left distributed cognition, explained in the following section.

Distributed Cognition

Groups of people have different properties than the individual group members (Hutchins, 1995) because team members trying to solve a common problem collaboratively have different experiences and skills, and thus know different things, allowing them to share their knowledge when working together. The group's team members also have shared knowledge, making them aware of what others are doing and this facilitates coordinated action (Rogers, 2006).

In the late 1980's, Hutchins examined this phenomenon of shared knowledge and proposed what he called Distributed Cognition (Hutchins, 1995). Distributed Cognition is based on cognitive science and on Vygotsky's socio-cultural approach to psychology (Hutchins, 1995). Distributed cognition argues that 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, Hutchins, & Kirsh, 2000). Distributed cognition strives to explain the interactions and exchanges of information between these environments and the individual. Distributed cognition is a theoretical framework that allows studies of cognitive processes in dynamic systems to help improve task performance (Hollan et al., 2000). These processes make distributed cognition a useful theoretical framework for examining the interactions among people, and between people and computers.

To gain an understanding of the properties of group work, researchers examine people's activities, communications, and artefact interactions through detailed ethnographic study (Rogers, 2006). In addition, examining the interactions between humans and technology gives an understanding of the role and function of that technology (Kirsh, 2004; Rogers & Brignull, 2003).

Researchers guided by the framework of distributed cognition strive to explain what happens between people and artefacts when they interact, and identify problems that may emerge (Rogers, 2006). Distributed cognition allows for the examination of the interaction between humans, groups, and artefacts, enabling the study of interaction between humans and software prototypes. This made distributed cognition a suitable framework that guided the research in this thesis, because it helped build an understanding of how commanders in the CBRNE command post work together and with PROBE. With distributed cognition as the theoretical framework, a method was necessary to examine it and get an understanding of teamwork and communication in the CBRNE command post. Distributed cognition among the CBRNE management team and PROBE was examined using Cognitive Ethnography, which is described in the next section.

Cognitive Ethnography

In addition to distributed cognition, Hutchins also coined the term 'Cognitive Ethnography' which originates in social and cultural anthropology, in which a researcher spends a lot of time in the field (Lewis, 1985). Cognitive ethnography provides data that distributed cognition explains (Hollan, Hutchins, & Kirsh, 2000). It assumes that human communication and activity, as well as breakdowns, are meaningful and culturally determined (Hutchins & Palen, 1997). In addition, cognitive ethnography can also serve to analyze how artefacts are used (Williams, 2006), which makes it an effective data collection method by which to inspect interactive systems (Dubbels, 2011). As this thesis aims to gain an understanding of teamwork and communication in a command post where an advanced prototype supporting management was used, cognitive ethnography was used in the data collection process.

The data required the researcher to understand communication, action, and the use of artefacts, can be gathered in many ways (Hollan et al., 2000). However, such understanding is usually acquired through detailed observations (Williams, 2006). Only with observational analysis can researchers who are guided by cognitive ethnography uncover what a specific technology product means to the users interacting with it and understand how these meanings are created (Hollan et al., 2000).

The detailed observations required for cognitive ethnography are usually documented over a long period of time, providing a lot of information about the people being observed but taking more time to acquire data than many other research methods, for example, interviews.

Unfortunately, because of the effort and expense associated with CBRNE event training, simulations are not run often and do not last long, because the participating personnel are on their normal duty at the same time, which can interfere with the training. For example, during a simulation, if the team receives an actual CBRNE call, it can result in unexpected changes in some of the personnel. Researchers must capture all the data as these emerge during the exercise. Therefore, one general disadvantage for cognitive ethnography is that it focuses on one specific instance and the conclusions derived from it are not generalizable as they only give in-depth knowledge of the particular context and situation under study. However, since this thesis is a continuation of a previous project where a different simulation was observed, this alleviates that disadvantage to some extent. Also, because the management support system will be used exclusively in CBRNE events, this specific purpose reduces the need to generalize to other types of event management situations. Therefore, cognitive ethnography was selected to guide the observations and data collection in this thesis.

With the observations being guided by cognitive ethnography, it is also necessary to discuss factors that underlie effective teamwork, detectable from live observations. Since the purpose of this thesis is to understand teamwork and communication in a CBRNE command post, is it important to examine what enables cohesive team work among commanders. Thus, the next section introduces the notion of teamwork during a CBRNE event.

Teamwork

Teamwork is essential in CBRNE event management, where there are several teams and team members working together to manage a crisis. Teamwork is the interaction of two or more individuals working together to accomplish a common goal (Kozlowski & Bell, 2003). The common goal in a CBRNE event is the management of the crisis (Moynihan, 2009). Effective and safe teamwork is crucial in many fields of work. For example, teamwork is essential in healthcare, the military, and disaster management (Baker, Day, & Salas, 2006). It is learned and practiced (Wallin, Meurling, Hedman, Hedega, & Fellander-Tsai, 2007), especially when the accomplishment of the goal is complex, as it is when managing a CBRNE event. To help achieve the given goal, tasks are assigned to each individual team member, much like each agency's responsibilities which are divided among its members. Effective teamwork entails realizing these tasks, which requires effective team coordination and collaboration (Reddy & Spence, 2008), facilitated by extensive information exchange in the form of communication (Mickan & Rodger, 2005). Communication facilitates teamwork by allowing the sharing of information. Information sharing enables the planning of actions, permits the forwarding of updates to alter action plans (Hazlehurst, McMullen, & Gorman, 2007), and it can also help teams recover from interruptions (Orasanu, 1994). All of these are necessary in CBRNE events for accomplishing tasks and achieving the common goal of managing the crisis.

Teamwork effectiveness can be measured by examining communication between team members (Bowers, Jentsch, Salas, & Braun, 1998). Because communication is central to effective teamwork during CBRNE event management, it is discussed next.

Communication

All verbal communication has the common purpose of sharing information (Parush et al., 2011). Verbal face-to-face and radio communication are relied upon in the CBRNE command post because the commanders are often collocated, and computerised systems are limited in such settings (Humphrey & Adams, 2011). Without verbal communication in the CBRNE command post, team coordination would suffer greatly or could even break down entirely. In situations as important as CBRNE event management, accurate information exchange and transfer is critical for an efficient response because it builds and maintains knowledge of the situation (Kramer, 2009). Team coordination is made possible by communication because it facilitates teamwork (Gorman et al., 2006).

Instances of communication can vary in effectiveness. Instances of effective communication occur when the meaning of a message is successfully conveyed from speaker to listener. One of the most common examples of an instance of effective communication is *closed loop* communication, which may be broken down to three main parts. First, the speaker initiates a message. Second, the intended listener receives, interprets, and acknowledges receipt of the message. Finally, the speaker ensures correct reception and interpretation of the message (Salas et al., 2009). An instance of closed loop communication could proceed something like this in a CBRNE command post: 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 thesis, instances of effective communication were operationalized as closed loop communication.

Not all instances of communications are effective, however, and breakdowns can occur. 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 the effectiveness of teamwork and hence also of team performance. Breakdowns can also occur in the form of interruptions, which are very important during a CBRNE event because they can serve to update team members on the constantly changing environment. For example, imagine that two commanders are planning the next step of the response when an update is radioed in to them about a new chemical identified in the hot zone. This allows the commanders to change plans accordingly and immediately. Interruptions from the responder teams can therefore be beneficial to management in the command post team. Interruptions are necessary, as there would be little or no progress in the shared understanding and knowledge of the event without them. However, event management could suffer if the interruption is not managed appropriately. Mismanagement could occur 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 from their radio to other members of the command post may not have all information of the current status of the event. In all this commotion, information communicated among commanders may be incorrect, messages may be overlooked, missed, or forgotten, all of which may lead to decrease the effectiveness of the emergency response.

Another instance of ineffective communication is *open loop* communication. Open loop communication starts when a speaker initiates a message, which is then either not received, not interpreted, or the intended listener fails to acknowledge it (Salas et al., 2009). An example would be an unanswered question. Important information is potentially lost when a question is not answered. This can be disastrous if, for example, information is about another bomb discovered in one of the nearby buildings and no one acknowledges the update in time to respond to the threat and ensure it does not detonate. Communication breakdowns such as open looped communications increase the probability of errors. For the purpose of this thesis, several kinds of ineffective communication were analyzed, including ineffective timing, and key individuals not being informed, and open loop communication.

In order 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 that are most readily uncovered by examining communication breakdowns. A good diagnostic measure would determine the causes of effective and ineffective communication instances, thereby helping to analyze responder performance during simulation-based training. Effective performance exists when each team member is aware, for example, of the accurate number of casualties enabling the commanders to order the corresponding volume of PPEs needed. Inaccurate or incomplete information can cause miscommunication further down the line, such as ordering far too many PPEs because the person ordering these did not get the message of the actual number of casualties. Analysis of breakdowns will provide information on teamwork and communication. Therefore, a useful analysis method should be able to identify these breakdowns in communication, enabling the researchers to focus on finding a solution to each type of breakdown. Accordingly, the next section discusses possible analysis methods.

Identifying Suitable Analysis Methods

Several analysis methods were considered to gain a better understanding of communication and teamwork in a CBRNE command post. Two aspects in particular were important in this thesis: the type of utterance instance, needed to pinpoint communication breakdowns, and the topic of communication, to help researchers understand what the instances of communication were about. The candidates considered were social network analysis, content analysis, and communication analysis.

. Social network analysis examines two types of properties: relational and structural (Streeter & Gillespie, 1992). Relational properties describe how resourceful the social units are, how influential they are to each other, the status between social units, and how important the social units are to each other. Since this thesis deals with commanders of equal importance to the event response, with known responsibilities and roles, relational properties were considered irrelevant. Structural properties include the number of members in the network, the degree of a social unit (i.e. how many people one person communicates with during an event), the distance between two individuals (i.e. the number of communication interactions that need to occur in order to connect two social units), and others (Streeter & Gillespie, 1992). While a social network analysis was conducted for this simulation, it has been reported elsewhere (Stojmenovic, 2011). Therefore, the results of that analysis were only summarized briefly in this thesis.

The remaining two candidates were communication analysis and content analysis. Communication analysis is used for qualitative data that focus on the type of utterance, which helps researchers pinpoint ineffective instances of communication. For this reason, it was applied to the data in this thesis; it is reviewed in the next section.

Content analysis focuses on the topic of communication and helps researchers identify the meaning of the instances of communication. The nature of content can be considered manifest or latent. Manifest content is easily observable (Rourke, Anderson, Garrison & Archer, 2001) and quantifiable, making it analyzable via quantitative content analysis. Based on verbatim transcripts, it can measure the active participation of individuals by counting the number of times an individual spoke, the interaction of individuals, based on how many times one person communicated with another, and the frequency of use of particular words. For example, much like in SNA, noting how many times one person addressed another by name can easily be traced by using quantitative content analysis. However, numerical data do not intuitively help to understand communication and communication breakdowns (Stojmenovic et al., 2011). Thus, this quantitative method was not applied to the current study. Instead, latent content analysis was applied as it is often descriptive, and has been previously applied to CBRNE event data (Stojmenovic et al., 2011).

Two qualitative analysis methods were thus chosen to analyze the data: communication analysis and latent content analysis. Both of these analysis methods were applied to identify communication breakdowns, which are needed to acquire a well-rounded understanding of communication and teamwork in a CBRNE command post, consistent with the purpose of this thesis. Communication analysis is described in the next section. This is followed by a description of latent content analysis.

Communication Analysis

Communication analysis can be used to map and understand teamwork (Parush et al., 2011). It involves the categorization of utterances into content (e.g. equipment, personnel, offending agent, etc.) and type of utterance (e.g. question, answer, etc.; Kramer, 2009; Parush et al., 2011). Hazlehurst and colleagues (2007) studied coordination and collaboration among team members in a hospital environment by focusing their analysis on only the type of verbal exchange. Similarly, the communication analysis in this thesis focused on the type of verbal exchange. The types of verbal exchanges were acquired from the CBRNE simulation, as they emerged from the verbatim transcript of the entire event. The type of instance of communication provides information on the information flow by demonstrating when information is needed (e.g. question) and when information is being shared (e.g. update). Sequences of communication types were examined for instances of effective and ineffective communication. For example, a question that was not answered was marked as a communication breakdown. The content of communication in the CBRNE simulation was also analysed as discussed in the next section.

Content Analysis

Content analysis is a widely used data analysis technique (Hsieh & Shannon, 2005). The content (or topic) of communication is another aspect of communication necessary for a thorough assessment of communication and teamwork in a command post. Latent content is often descriptive. It is not directly observable and must typically be uncovered from transcripts. Examples include the use of humour which depends on context and cultural interpretation, critical thinking, judgment, initiative, and other cognitive dimensions (Rourke et al., 2001). Therefore, these data require qualitative content analysis. As is true for quantitative analysis, coders apply a systematic classification process to discover themes in the data while reading transcripts (Hsieh & Shannon, 2005). This systematic classification is used subjectively to interpret the meaning of the text content (Pope, Ziebland & Mays, 2000; Wong, 2008) because two researchers might interpret the same data differently. The difference is that manifest content analysis categorizes easily quantifiable properties (e.g. counting the number of times a certain word was used), whereas latent content analysis requires interpretation of data before categorization (e.g. to interpret a sentence as a joke before it is classified as such). Once the data for this thesis had been interpreted and coded, evidence for communication breakdowns were uncovered to get a better understanding of communication and teamwork in the CBRNE event management environment studied here.

Qualitative content analysis creates categories as its defining feature (Graneheim & Lundman, 2004). A category is internally homogeneous because the content within a category has something in common, while it differs from other categories, making it externally heterogeneous (Graneheim & Lundman, 2004). Categories may be derived by induction or deduction. Deductive analysis starts with certain types of communicative behaviours and then sorts the transcript data into those pre-defined categories. This process limits the number of categories so that the analysis is more focused. However, it can also exclude important data that were not considered at the beginning. Using inductive analysis, a researcher gradually generates categories directly from transcripts. This process can be considered inclusive because categories are added so that all details in the data are kept (Pope et al., 2000). Since there is a danger that valuable information may be lost because it may not be considered when using deductive analysis, latent inductive content analysis was used to identify relevant management issues for the understanding of communication and teamwork in the CBRNE management simulation studied here.

Regardless of whether inductive or deductive content analysis is chosen, a unit of analysis must be designated ahead of time. A single unit should convey a single item of information extracted from the content (Rourke et al., 2001). A sentence, a paragraph, and a message are all objective units of analysis in transcripts. In this thesis, a sentence was used as the unit of analysis as it is the smallest unit of communication that conveys the most meaning.

The research in this thesis involved collecting and analyzing CBRNE event data to understand teamwork and communication in the command post by focusing on identifying and interpreting communication breakdowns. It therefore falls within the realms of exploratory work. For that reason, no hypotheses were proposed. Both communication analysis and content analyses were used to uncover and understand instances of ineffective communication, by analyzing the type of utterance and content of communication as they emerged from the data. The type and topic of utterances were also related to two other contextual factors: speaker and procedure phase. The application of both analysis methods to examine communication during the CBRNE simulation allowed a thorough analysis; instances of effective and ineffective communication were identified by communication analysis and the meaning of the communication instances were identified by content analysis. These two aspects of communication enabled the researcher to acquire an understanding of communication and teamwork in a CBRNE command post. In order to check the reliability of the categorization done by the researcher, another researcher coded the data, discussed in the next section.

Calculation of the Inter-rater Reliability

There are over thirty different agreement indices that are used for the coding of categories (Popping, 1988). The most widely used include percent agreement, Holsti's method, Krippendorff's alpha (a), Fleiss's kappa, and Cohen's kappa (k). There is little agreement among researchers as to which method is the best (Lombard, Snyder-Duch, & Bracken, 2010). Percent agreement and Holsti's method can overestimate the inter-rater agreement by not accounting for agreement that occurred by chance (Lombard et al., 2010). Not all statistical software applications have the option to compute Krippendorff's alpha, yet it involves tedious calculations if found by hand. Fleiss's kappa is used when there are multiple raters, while Cohen's kappa is typically used when there are only two (Lombard et al., 2010). In addition to being widely used, Cohen's kappa is also relatively simple to compute by hand. Conceptually, kappa is equal to the proportion of agreement actually observed between raters, after adjusting for the proportion of agreement expected by chance (randomly). For this reason, some refer to kappa as the chance-corrected proportion of agreement (Berry & Mielke, 1997). If the kappa value is below .41, it is a weak inter-rater reliability. If it is between .41 and .60, then the inter-rater reliability is considered to be 'moderate' (Burla et al., 2008). If the calculated Cohen's kappa is between .60 and .80, then it is deemed 'satisfactory', and if kappa is above .80, then the inter-rater reliability is almost 'perfect' (Burla et al., 2008). As Cohen's kappa is often used in behaviour-coding research (Bakeman, 2000), it was used to calculate inter-rater reliability in this thesis.

Summary

CBRNE events pose a serious threat to society. The goal of this thesis was to gain an understanding of teamwork and communication in the command post during such an event. The officials in charge of managing the simulated event used an advanced management support system prototype called PROBE, capable of supplementing and recording communication, both for event management and for documentation purposes. The theoretical and methodological framework that guided the research in this thesis were distributed cognition and cognitive ethnography. The transcript was coded by communication analysis and latent inductive content analysis to uncover content and type of utterance, as they emerged from the data. The coding reliability of these methods was separately checked by the calculation of Cohen's kappa, for each analysis method. Both analysis methods were conducted to obtain an understanding of breakdowns in communication, and ultimately, teamwork and management in a CBRNE event environment.

Method

Participants

A total of 14 experts participated in the study, representing 3 hazardous materials (hazmat) experts, 3 emergency medical service (EMS) officers, 3 police officers, 2 PROBE scribes, 2 event coordinators, and one software developer for PROBE. Of these, five were in the command post (one EMS commander, one hazmat commander from the fire department and his scribe, and the IC from the police department with his scribe), three were Ops officers (one per agency). The scribes' role was to transcribe into PROBE what the commanders ordered should be communicated to other members of the response team. While the IC was in charge of managing the CBRNE event-related threat, the event coordinators were in charge of managing the logistics of the simulation, such as monitoring the progression of the scenario, and planning lunch. Participation in the simulation was a part of their jobs; permission of the researchers to be present had been granted a priori by all concerned. Participants were not compensated by the researchers. The event lasted five hours.

Design

Two researchers focused on the command post members during the simulation. At all times during the training simulation both researchers observed activities in the command post as a whole, from opposite sides of the room.

Materials

The informed consent form can be found in Appendix A. The introduction given to participants before the observations can be found in Appendix B. The debriefing form for the observations can be found in Appendix C.

Apparatus

Each researcher was equipped with a video camera (Sony Handyman DCR-SR-300 HDD) and there were three stationary audio recorders (Olympus WS-311M Digital Voice Recorder) in different areas of the command post. The command post was equipped with four laptop computers, one for each of the three commanders (EMS, hazmat, and police) and the fourth was set up for the event IC.

Each commander had a radio running at a unique frequency. There was also a radio in the command post that allowed the commanders to listen to communication between the Ops officers. As far as possible, these conversations were captured. Once the utterances were categorized, the codes were transferred to NVivo version 9.0 for further analyses. All tables in the results section were created in NVivo 9.0.

Procedure

First, the purpose of the researchers' presence and task was explained to participants by the event organizers. Then, participants read and signed the informed consent form. During the event, commanders in the command post were observed. Verbal interactions between command post members, and between commanders and their Ops officers (in person, radio, and software communication) were recorded. At the end of the event, all commanders were given debriefing forms, the purpose of the recordings was repeated, and they were thanked for participating.

Data Analysis

In an effort to re-construct the entire event, the video and audio recordings were transcribed ad verbatim and merged into a single file, to compare activities across all command post participants at any point in time during the exercise. All recordings were viewed multiple times to identify and verify the identity of the speakers and listeners of verbal communications. In order to focus the analysis, any conversations unrelated to the event management were removed from the transcript to enable further analysis.

Table 1

Format of the Transcript used for Data Analysis

Time	Source	EMS	Police	Hazmat
10:33	Viedo File: 141203	Radio1 (X): Can I get an update on XYZ? X (Radio): Yea, XYZ has been ordered and is		Radio2 (Y): Exercise, exercise exercise -

	on the way.	Z (Radio3): It's	Haz responding.
		green and blue.	
10:34	Radio1 (X): Thank you.	Right?	

The format of the transcript was similar to that used in the previous study. It was formatted into columns to help organize simultaneous conversations, as shown in Table 1. Table 1 shows the time of observations in the leftmost column. The second column from the left gives the source of the original data (video/audio and file name). Data obtained from each agency is in the three rightmost columns.

From the transcript, teamwork and communication effectiveness were assessed by analyzing team coordination and reactions in response to unexpected changes in the environment, such as interruptions, using communication analysis and content analysis. For both analysis methods, the researcher viewed the videos and read the transcripts, focusing on what each of the commanders was saying and doing as they coordinated their actions with the other members of the command post. For the communicating analysis, the researcher focused on the type of utterance, and for latent inductive content analysis, the researcher focused on the content (or topic) of communication.

Using the same categories as a guide, another researcher independently categorized each sentence from a randomly selected 10% of the transcript by type and content of communication, to assess the inter-rater reliability using Cohen's kappa. The first calculation was reported, with negotiation following to settle any disagreements between the two raters. All utterances were coded digitally. Both verbal and non-verbal communications were noted. Finally, meaning was extrapolated from the categories to analyze and compare the instances of communication breakdowns, in order to acquire an understanding of communication and teamwork in a CBRNE command post.

Results

There are five sections in the results. The event description is provided first. The findings of the communication analysis are presented second, where the instances of ineffective communication were found. This is followed by the content analysis results, where the severity of the instances of ineffective communication was assessed. Then, the inter-rater reliability of the two analysis methods is presented. A summary of the findings from the Social Network Analysis is given next, followed by a summary of the speaker-related communication results. Lastly, the CBRNE simulation event management goals are presented. The implications of these results are discussed in the discussion section.

Event Description

In May 2010, a half-day CBRNE simulation exercise was staged in Saint John, New Brunswick. The event took three hours. The EMS, hazmat, and police Ops officers were located in the warm zone, along with the decontamination tent, and the two researchers observing the simulation were located in the command post in the cold zone (see Figure 4, p. 9).

According to the scenario, police officers had arrested some suspects at the Port of Saint John, and a search of the area had led to the discovery of a makeshift lab in one of the on-site storage containers. This area was labelled the hot zone. The police officers notified their superiors and, as in a real situation, a unified command post was set up to collate all of the necessary information and to manage the emergency response from the cold zone. The data were divided into two Phases, approximately splitting the simulation into two equal halves, each lasting an hour and a half. This division corresponds to the two separate Incident Action Plans that 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 of the situation. Hydrochloric acid and potassium cyanide were found and neutralized by the first responders. Later in Phase 1, another threat was discovered - an activated bomb. Phase 1 ended with the deactivation of the bomb and the extraction of victims from the hot zone. Phase 2 then involved the planning and execution of the second Incident Action Plan, for the re-entrance of police and hazmat first responders into the hot zone for evidence collection and cleanup. EMS officers remained on standby in the warm zone, just in case.

Communication Analysis Results

The communication analysis focused on the type (e.g. question, answer, etc.) of utterance, and was divided into two steps. The purpose of the first step was to code each utterance by type, as types emerged from the raw transcript data. The purpose of the second step was to examine sequences of communication types for instances of effective and ineffective communication. The results of these two steps are provided next, followed by the results of content analysis.

Step 1 of communication analysis: coding results. In the first step, a total of 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 types of utterances uncovered in the transcript. The definitions of acknowledgments, answers, explanations, jokes, statements, suggestions, and updates are partially adapted from Stojmenovic and colleagues (2011). All utterances in the transcript were coded as one of these communication types shown below.

Table 2

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

Utterance Type	Definition	Example
[illegible]	[illegible]	[illegible]
Answer	Responses specific to questions.	It was red.
Attention Granting	[illegible]	Ops (K): Go ahead.
Attention Request	Demands for awareness, from speaker to listener, precedes a communication.	HCo (HOp): Operations officer, this is fire in command.
Clarification Granting	Clarifying or rewording a previous communication.	Yes, today.
Clarification Request	Asking for clarification on a previous communication.	Do you mean today?
Complaint	Expressions of discontent.	I would never use this. Its 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.

A summary of the communication analysis findings for both Phases is given here, but complete results of the Phase 1 coding process is provided in Appendix E, and Appendix F shows the complete coding results for Phase 2. Table 3 below shows the frequency of each utterance type for Phases 1 and 2. The leftmost column shows the type of utterance; the middle two columns show the frequency with which each utterance type occurred in Phase 1 and 2. The rightmost column in Table 3 shows the total frequency of occurrence of each type of utterance, throughout the entire CBRNE event.

In general, the communication volume was fairly similar in Phases 1 and 2, as seen in Table 3. This was surprising because, anecdotally, there seemed to be more activity in Phase 1 in which the chemical was neutralized, victims were found and removed from the hot zone, and the bomb was deactivated. Thus, the most dangerous parts of the CBRNE event were dealt with in Phase 1, which should have warranted a high frequency of communication, allowing commanders to organize the response. This should have accounted for the majority of communications, leaving little need for activity in Phase 2. However, as seen in Table 3, this was not the case, as the commanders were more involved in planning and altering the second incident action plan for re-entry into the hot zone for cleanup and evidence collection than they were for the first incident action plan. In Table 3, the items that belong together conceptually have been placed together. For example, questions are followed by answers in Table 3.

Table 3

Communication analysis types of utterances during the CBRNE simulation

	Event Phase		
Utterance Type	Phase 1	Phase 2	Totals
Acknowledgment	129	165	294
Question	185	158	343
Answer	162	132	294
Attention Request	38	56	94
Attention Granted	30	39	69
Clarification Request	25	24	49
Clarification Granted	20	22	42
Explanation	74	63	137
Order	21	14	35
Repetition	32	25	57

[illegible]	[illegible]	[illegible]	[illegible]
Suggestion	12	11	23
[illegible]	[illegible]	[illegible]	[illegible]
Complaint	38	19	57
[illegible]	[illegible]	[illegible]	[illegible]
Totals	988	909	1897

There were a total of 1897 utterances in the entire simulation, as seen in Table 3. Questions were asked most frequently in Phase 1, closely followed by statements, answers, and acknowledgments. By contrast, acknowledgments were the most frequently occurring type of utterance during Phase 2, followed by questions, answers and statements. Questions were expected to comprise the most frequent type of utterance in Phase 1, 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. As questions demand answers, the number of answers was also amongst the most frequently occurring type of utterances as well. However, if all questions had been answered as in closed-loop communication, the number of answers should have been equal or almost equal to the number of questions. Instead, the data suggest that there were several instances of ineffective, open-loop, communication. These are discussed in more detail in step two of the communication analysis.

Statements occurred frequently because all facts and ideas were categorized as such during the event. There is a possibility that statements could have been mistaken for answers to questions in some instances. However, the utterance definitions were believed to be unambiguous and enabled the researcher to distinguish between answers, statements, explanations, clarifications, etc. The issue of definitions is taken up in the discussion of the inter-rater reliability calculations.

Explanations were elaborations on any utterance, raising their frequency as many utterances such as answers and statements were followed by explanations. Acknowledgments also occurred frequently in both Phases. This could have occurred because acknowledgments were general responses to all types of utterances except attention requests and questions, informing the speaker that the listener had received the message. Thus, acknowledgments occurred frequently because they were the universal response to utterances, often closing the loop in communications. The most frequent acknowledgments were: "yea", "ok", "roger", and "10-4", as seen in Table 2. Communication analysis requires the researcher to categorize each utterance in isolation. The context was therefore missing, requiring the analysis of sequences of utterances, which is described in part two of communication analysis.

Utterances were coded as repetitions when a responder forwarded newly learned or planned information down the chain of command. Both updates and repetitions occurred with medium-to-low-frequency. It was anticipated that more of these would occur between the commanders and the Ops officers, because newly acquired information would help plan the response, and the plan needs to be passed down the chain of command. However, the commanders' main function in this event was to approve the incident action plans. This required less updating from the Ops officers because main details were grouped together in the action plans. Commanders talked about these action plans, and then forwarded the documents, again grouping many details together and reducing the need for repetitions.

Clarification requests and grants did not occur frequently. In both Phases, when an utterance, such as a question, was not understood or properly heard by the intended listener, the listener would request a clarification. The clarification request resulted either in a repetition of the utterance or in rephrasing. For example, the EMS commander asked the PROBE developer if "[the IC] has [the incident action plan] as well?" to which the developer responded with a clarification request "Sorry?", which was followed by a clarification: "[the IC]. He has access [to the incident action plan] as well?", and the developer finally answered the original question "oh yea, that's pretty well standard." Therefore, clarification grants only followed clarification requests, when preceded by a different utterance, not understood or heard by the listener. Far more clarification requests occurred than clarification grants, especially in Phase 2, suggesting the possibility of open loop communication.

In a command and control environment, such as a CBRNE event, one would expect many orders and suggestions. However, this was surprisingly not the case. Although the number of suggestions is low in both Phase 1 and 2, the commanders rarely gave orders or suggestions to the Ops officers. As became clear during the data analysis, this occurred because the commanders' main role was to communicate for the purpose of acquiring information on what was going on in the hot zone and to approve the incident action plans. Acquiring information happened mainly through questions, answers, and updates.

Jokes and complaints were the two least frequent types of utterances throughout the event. This was expected as they do not play an important role in the management of a CBRNE event. An example of a joke was when a scribe asked the IC: "Do you need to send a message right now, one to the police saying firemen are awesome?" While jokes occurred infrequently, they helped lighten the mood in the command post. Complaints were mainly about PROBE and not related to the event management. Communication topics will be discussed in the content analysis section.

In summary, types of utterances unexpectedly occurred with similar frequencies in both phases of the CBRNE simulation, regardless of the level of complexity of the action plans by which the phases were divided. The most frequently occurring utterances were questions, answers, acknowledgments, and statements, and the least frequent utterance types were suggestions and orders. In order to determine the effectiveness of communication, the next section discusses the findings related to the sequences of utterance types.

Step 2 of communication analysis: analyzing sequences. Since communication analysis requires the researcher to examine each utterance in isolation in order to categorize it by type, instances of effective and ineffective communication were not readily found by that method. To achieve that, sequences of communication belonging together were therefore identified and classified. Of all instances of communication, 136 in Phase 1 and 133 in Phase 2 (total 78.9%) were effective. While the majority of communication was effective, it is evident from Table 4, that there were also some instances of ineffective communication in both Phases. Six types of ineffective communication were identified as shown Table 4 showing the number of instances of effective and ineffective communication during the simulation. The leftmost column shows the number of instances of both effective and ineffective communication. The middle two columns show the frequency with which the instances of communication occurred in Phases 1 and 2. The rightmost column shows the overall frequency of effective and ineffective instances of communication, throughout the entire CBRNE event. Each of the ineffective communication types is discussed below.

Table 4

A total of all instances of communication during the CBRNE simulation

	Event Phase		
Instances of Communication	Phase 1	Phase 2	Total
Effective Communication	136	133	269
Ineffective Communication	39	33	72
Open Loop	8	18	26
PROBE Error	14	3	17

[illegible]	4	6	10
Time Lag	5	4	9
[illegible]	4	2	6
Incomplete Information	4	0	4

Open Loop Communication. As Table 4 shows, open loop communications was the most frequently occurring type of ineffective communication, with more than double the number of these occurring in Phase 2 than in Phase 1. These occurred in the forms of unanswered questions, unfilled clarification requests, unattended and requests for attention, and unacknowledged communication. While open loop communication may seem obvious from the frequencies in Table 4, it is important to note that, for example, not all unanswered questions were instances of open loop communication. For example, when the conversation continued and the listener could deduce the answer from a series of explanations or statements, it was not categorized as an instance of ineffective communication. In addition, because the commanders were collocated in the command post, closing a verbal response was not always necessary, as nonverbal communication, such as facial expressions and reactions, that the message had been responded to, were able to close the loop. Unfortunately, communication analysis does not take nonverbal communication into account. However, the researchers in the command post were located in opposite corners of the room, behind the commanders, so as to not get in the way. Thus, the video recordings mainly captured the commanders' backs and their interactions with PROBE, making it impossible to capture and hence to analyze nonverbal behavior such as facial expressions.

As mentioned earlier (pp. 36), the number of unanswered questions was very similar in the two phases. One example of that was when the hazmat commander requested a situation status update via radio from his Ops officer. This question was never answered or acknowledged. A meeting was supposed to be held well in advance of that question but was forgone in order to focus on testing PROBE. In order to get the situation status update, the meeting was rescheduled and held later. In some cases, unanswered questions were simply not heard. In other cases, two people were involved in communication when a third person asked a question. At times, the conversation continued and the question was ignored, perhaps because it was not heard or forgotten. In both Phases, a small number of clarification requests were not followed by clarifications. For example, when one of the two event coordinators asked which personnel a commander was talking about, he never received a reply. Some clarification requests were not followed by clarifications because they were not heard, or the conversation continued and the request was forgotten. The same was true for attention requests. As seen in Table 3 (p. 36), there were more attention requests than were granted. One such request occurred when the IC called his Ops officer via radio to ask a question, and the Ops officer did not respond. As the researchers were located in the command post and no data were collected on the other layers of the response management, the reason for the lack in response is unknown. Unattended requests for attention hindered information exchange because communication could not proceed without the attention of the listener. Therefore, it is possible that pertinent information was not shared because potentially important updates or requests for information did not proceed. However, since the Ops officers were not observed, the consequences of these are unknown. In addition, there were fewer acknowledgements than anticipated given the number of all the other utterance types (e.g. statement, answer, etc.) that would seem to demand an acknowledgement. However, because of the collocation of commanders, who could also rely on nonverbal communication, the apparent lack of acknowledgments did not cause instances of ineffective communication. It would have been beneficial to analyze these nonverbal communications instances as well, as they may have clarified instances in which an acknowledgement would have been expected.

PROBE-related issues. Two types of ineffective PROBE-related communication were identified: lack of familiarity with PROBE, and software shortcomings/mishaps. The main issue was that not all communications were being 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 one-day PROBE training session the day before the event, but 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, needing to be refreshed manually. The EMS commander who did not rely on a scribe as the other commanders did, had forgotten this. She attempted to communicate with the EMS commander via PROBE, but the messages were not received because of the need to refresh the incident report page needed to be refreshed manually. The EMS commander thought that the IC scribe was not forwarding relevant information, leaving the EMS commander searching for information and relying heavily on radio communication for a large part of the event response. Once the PROBE developer reminded her that the screen had to be refreshed to receive updates, this problem was solved, and the EMS commander was flooded with the previously missed messages. Thereafter, she referred to her error as an "I.D. ten T. error", written as "I.D.10.T. error". While most PROBE functions did work, the sending and receiving of attached files, such as the incident action plan, was not working. That delayed the sharing of information as the hazmat scribe noted by saying, "So I exported something to him, but he hasn't got it." There are two possible reasons for why messages were not received when sent via PROBE. One is that users did not remember how correctly to send messages, and the other possibility could be 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 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. Therefore, several instances of ineffective communication were due to problems with PROBE. The severity of these problems is addressed in the latent inductive content analysis section.

Misunderstandings. There were 10 instances of misunderstandings, seen in Table 4 (p. 40). One occurred at the beginning of the simulation, when the command post team thought that the CBRNE simulation had begun because the ops officers had a meeting. Realizing that it was not the case, one if the commanders said: "I thought we were live, apparently, we're not."

Time lags. Some instances of ineffective communication were due to time lags. If the interval between an initiating utterance and a response exceeded one minute, it was considered a time lag. For example, the police Ops requested the IC's attention via radio, and the IC only responded a couple of minutes later, after being prompted by the hazmat commander that his officer called him.

Key individuals uninformed. Other examples of ineffective instances of communication occurred when key individuals were not included in a communication. For example, during a radio communication, the hazmat Ops officer informed the hazmat commander that he "never got the confirmation" that the incident action plan had actually been approved, which had been communicated in a previous message.

Incomplete. Some instances of incomplete utterances referring to key information missing were also identified. For example, the hazmat Ops officer requested a meeting with the other officers at the beginning of the event, without mentioning why the meeting would be held.

The commanders requested more information, saying "We've got nothing. We don't even know if there's a situation. ... I don't know what they were supposed to tell us, if there was a suspicious product or whatever. We've been given nothing other than [the Ops] wanted a meeting." This request for a meeting made the commanders believe that the CBRNE simulation had begun and that the Ops officers were already planning the response. However, the meeting was requested so that the Ops officers could introduce each other and to get aquatinted with each other's team members and man power, available for the simulation.

In summary, the most frequent types of communication were questions, acknowledgments, statements, and answers. This was expected as questions needed to be asked and answered while facts and ideas needed to be stated and acknowledged because accurate information exchange is critical for facilitating teamwork and ensuring an efficient CBRNE response. The least frequent types of communication were suggestions, jokes, requesting and granting clarifications, orders, and complaints. The small number of suggestions and orders was surprising because, as had been observed in the previous simulation that members of the HOTLab observed and analyzed, one would expect those to be frequent in a command and control environment. Although it is important to identify the number and types of utterances and utterance sequences, it is just as important to understand the meaning of these. The latent inductive content analysis facilitated this interpretation. It is therefore discussed next.

Latent Inductive Content Analysis Results

The latent inductive content analysis focused on the topic of utterance, and was divided into two steps. First, each utterance was coded by topic as it emerged from the data. Second, the instances of ineffective communication identified in the communication analysis above were examined to determine their severity.

Step 1: coding results. In total, seven content categories emerged from the transcript along with their definitions. Table 5 shows the content of the relevant utterances. The leftmost column shows the topic categories; the middle column shows the definition of each utterance topic, and the rightmost column shows an example of each topic. All of utterances were coded as one of these utterance topics.

Table 5

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.

A summary of the results is given in Table 6. Full details for Phase 1 are in Appendix G, and in Appendix H for Phase 2. A total of 1642 utterances were related to the topics identified. The number of topic utterances cannot be compared to the number of types of utterances because a single utterance could only be classified as one type. For example, a question could not also be an answer, although it could include multiple topics - it could be about both personnel and equipment. In addition, some utterances could not be related to a specific topic. For example, attention requests and grants were not categorized into topics because the topic of conversation was only revealed after the attention was granted and the conversation began. Along similar lines, a typical radio conversation would start with the speaker requesting the listener's attention. For example, "Fire command, fire ops". This would be acknowledged by granting attention. For example, "Fire ops, this is command, go ahead". Only then would the conversation proceed with a topic, such as the incident action plan, or equipment.

Table 6 shows the number of times a topic occurred during the CBRNE simulation. The leftmost column shows the utterance topic. The middle two columns show the frequency with which the topic occurred in Phases 1 and 2. The rightmost column in Table 6 shows the total frequency of topic utterances.

Table 6

Latent inductive content analysis category totals from the CBRNE event

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

Most of the participants observed spoke most frequently about PROBE, making it the most frequently mentioned topic during the entire event, as seen in Table 6. In fact, it accounted for almost one half of all utterances (48.9%). 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 PROBE. The overall popularity of PROBE is interesting in that it suggests that the command post team members were not preoccupied with the actual CBRNE mission as had been observed in the previous simulation. It was therefore expected that the communication would be centered on the action plan, equipment, and other response-related communication. The PROBE communications were only of marginal importance to the event outcome. In fact, 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. The hazmat commander told the event coordinator, "Right, and I did mention that, so that it's on the record, that we would have had a sit stat, but because everything was so – it was more about the technology." 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. Therefore, the commanders had more time to explore PROBE. Also, because the commanders 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. Some of these utterances resulted in ineffective communication, the severity of which is discussed later in this section.

The second most mentioned topic was planning the CBRNE event management. This was followed by personnel, event, equipment, communication, and the offending agent(s). The command post team makes crucial strategic decisions necessary to manage the event, making planning and revising the action plan their primary purpose, yet only 16.3% of communications were about that. The action plan was talked about more often in Phase 2 than 1 because the commanders changed the PPE suit level that the Ops officers had suggested in the second action plan, whereas the first one was not altered. This increased the frequency of communication about the second incident action plan in Phase 2, relative to Phase 1. However, the role the Ops officers played in managing the first responders in the hot zone, the deploying of equipment, and creating the incident action plan seemed to really diminish the need for much planning in the command post in this particular simulation, accounting for its low frequency of occurrence. The CBRNE simulation personnel was talked about more frequently in Phase 1, when commanders were getting acquainted with their own and each other's teams, and when clarifying the first entry team's members, suggested by Ops officers. Once everyone had an idea of who was part of the response team, less conversation was needed about personnel in Phase 2. Event management discussions, such as communication about lunch, doubled in Phase 2 because that is when the lunch and coffee breaks occurred. Discussions about equipment, excluding PROBE, stayed relatively constant. In Phase 1, the commanders discussed which team members would be on what radio channels, and in Phase 2, PPE was discussed for re-entry. Conversations about communicating with other members doubled in Phase 2, as commanders talked about notifying Ops officers 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. However, the lower frequency of communication about the CBRNE simulation was just as surprising as the frequency of communication about PROBE until the distribution of responsibilities among Ops teams and the command post team became clear. In addition, the finding that the event management was more frequently talked about in the command post than equipment or personnel also suggests that the Ops officers were experienced at their jobs, not requiring input from superior officers.

In summary, PROBE was the most frequent topic of communication in the command post. This was not expected as PROBE was of marginal importance to the management of the event. However, breakdowns in communication associated with PROBE did hinder information exchange, possibly impeding teamwork and efficient CBRNE response - making it a pertinent topic for discussion in the command post. As the Ops officers did the majority of the planning, the commanders kept CBRNE event-related communication to a minimum. In order to acquire a deeper understanding of the instances of ineffective communication, the next section discusses the second step of this analysis method, taken by the researcher.

Step 2: assessing the severity of ineffective communication. Once instances of effective and ineffective communication were found and the topic of each utterance had been identified, the severity of each instance of ineffective communication was analyzed. This was done by examining the topic of the instance of ineffective communication, along with examining the types and topics of utterances immediately following the ineffective communication, to identify the consequences of these. Although this level of analysis was not included in the content analysis literature, it allowed the researcher to examine the severity of the instances of ineffective communication.

In total, 23.6% of all instances of ineffective communication were PROBE-related. However, few of these instances of ineffective communication were detrimental, and did not result in communication breakdowns because commanders used their radios as backup when information was not coming in through PROBE. They requested confirmation of all communications, to ensure that the message was indeed received by the intended listener(s).

The only communication breakdown, which also had a severe consequence in Phase 2, involved the hazmat first responder entry leader and the Explosive Disposal Unit (EDU) officer in the hot zone who was running out of oxygen. These two first responders were dressed in high level PPE, which are air-tight safety suits for highly dangerous events, as seen in Figure 5. 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 one hour, but could be as short as 30-35 minutes depending on the level of the wearer's level of exertion.

Figure 5. A high level of personal protective equipment used in the CBRNE simulation

In Phase 2, 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. This incident only came up again almost an hour later, during the situation status update where all commanders and Ops officers were present, when the hazmat Ops officer elaborated on it. It was again clarified by the police Ops at the end of the day, during the debriefing session. According to both of these Ops officers, at that stage, the chemicals had been neutralized and the EDU and hazmat first responder were in the hot zone, waiting for forensics responders to make entry. The EDU officer had a weak radio signal preventing him from communicating with his team, relying instead on the hazmat first responder who was with him in the hot zone for relaying communication. The police forensics officers were waiting for the commanders' approval of the second incident plan before going into 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 another six minutes to approve the incident action plan, and entry was to take place approximately ten minutes 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 nine minutes later - two minutes later than the original ten minutes anticipated after the second action plan had been approved, as seen in Figure 6. The moment the IC received an update 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, three minutes before the second incident action plan was approved. This should have given the paramedic enough time to get ready and be in position by the decontamination area. The reason for the lack of his immediate presence and assistance is unknown. Other than that incident, "the exercise went excellent[ly]", according to the police Ops officer.

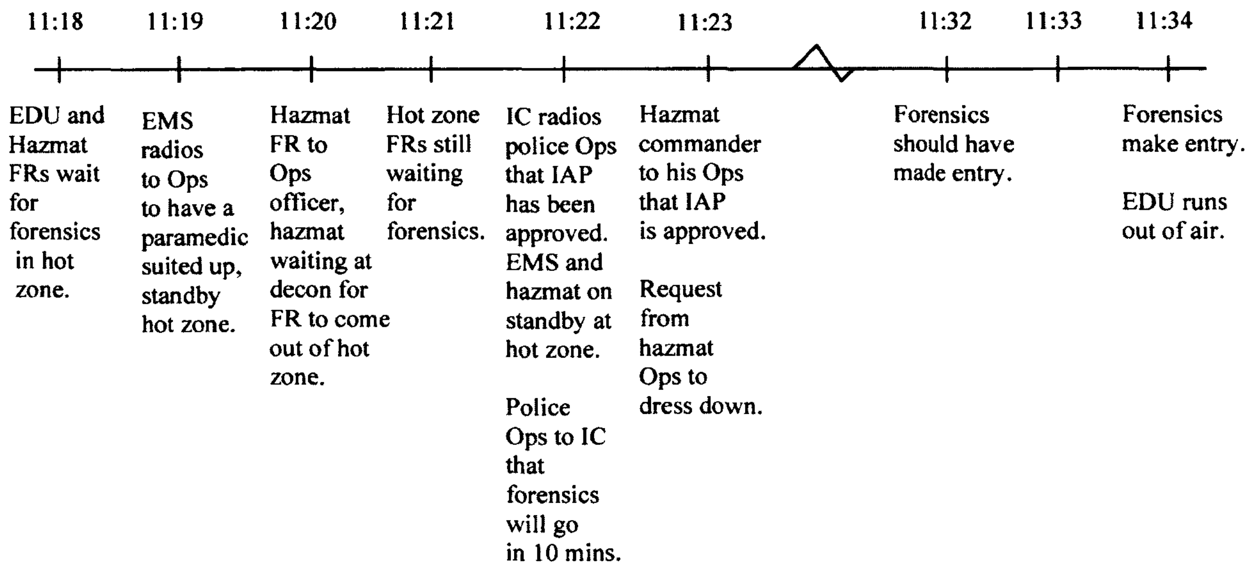

Figure 6. Timeline of events, as they emerged from the transcript.

Although most participants 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 summary instruction 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 kind 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.

Inter-rater Reliability Results

Inter-rater reliability was calculated separately for communication analysis and for content analysis. Once the entire transcript had been coded and all the codes had been identified, another researcher independently coded a random sample of 10% of the transcript by type and topic of communication to determine the inter-rater reliability. Before coding the data, the second researcher was given a description of the CBRNE simulation to provide some context to the transcript, as well as all codes, complete with unique definitions, as shown in Tables 2 and 5 below.

Communication analysis inter-rater reliability results. The percentage of agreement was 70.2%. Cohen's kappa, calculated by hand, was 0.5903, which is deemed moderate, almost satisfactory, as discussed earlier (pp. 27). The main discrepancy occurred because the second researcher forgot to include the 'question' and 'answer' categories, labelling them instead 'clarification request' and 'clarification granting', respectively. In addition, she systematically used the 'clarification granted' category when no clarification was requested; these should have been labelled 'explanation'. Therefore, the 29.8% of disagreement in labelling was settled together and the original rating was agreed to be correct, now resulting in a 100% agreement.

Latent inductive content analysis inter-rater reliability results. The percentage of agreement was found to be 62.9% for latent inductive content analysis. Cohen's kappa was calculated by hand and was found to be 0.5532, which is deemed moderate, as discussed earlier (pp. 27). The moderate reliability occurred because the other researcher was largely unfamiliar with the context or the concept of PROBE, so she labelled many 'PROBE' communications as 'equipment'. Considering the volume of communication that was about PROBE (48.9%; pp. 47), it is the main reason the inter-rater reliability was moderate. In addition, the other researcher mistakenly labelled responder names as 'personnel' when they were used for to seek attention and not the topic of the communication. Thus, the 37.1% of disagreement in labelling was settled and the original rating was agreed to be correct.

Summary of the Speaker-related Results

As a thorough SNA has been reported elsewhere (Stojmenovic, 2011), this section provides only a summary of the findings from that analysis is provided here. The geodesic distance between the three commanders was 1, because they were collocated and therefore able to communicate directly with each other. The sociometric status is a centrality measure of how busy a unit is relative to the other units in the network. In the present analysis, the hazmat commander and the IC had the highest sociometric status, that is, they were found to communicate the most. This was followed closely by the EMS Commander. This was to be expected, since observations were made exclusively in the command post. Most of the communication recorded was between commanders, with some exceptions of radio conversations and face to face communications with other responders.

The most frequent speaker was the hazmat commander, 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 command post. Because the hazmat commander was older than the IC, he probably also had more experience in the command post. At the very 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 his relative lack of 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, if was unclear if 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. On the other side, the teams out in the field are highly qualified and might have encountered something that they were able to handle without the help of superiors.

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 much attention. The EMS first responders duties were limited to monitor the vital signs of teammates going in and coming from the hot zone - a routine task for paramedics, not requiring a lot of communication. The full results of the speaker-related communications can be found in Appendix D.

CBRNE Simulation Goals Emerging During the Debriefing Session

During the debriefing session, the researcher discovered that the agencies had different agendas and goals in 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 as well as the police team members wanted to practice working with the other two agencies. The hazmat team was municipal, whereas the police personnel were not from Saint John. Some officers were from Halifax, the EDU team was from Fredericton, and there was another group of officials, including the IC, who were from the RCMP. Collectively, the police officers' goal was primarily to get practice coordinating with other sectors and agencies. The EMS team was from a provincial level in New Brunswick. The EMS team had two goals for the CBRNE simulation: testing 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 in large scale events were being changed, requiring new forms for the paramedics to support their taking of first responders' pre- and post-vital signs. The EMS's goal was to test the usability of the forms during this CBRNE simulation, which apparently passed the test successfully. Because of this, and despite her problems receiving messages from her ops officers, she thought that "[the simulation] overall went well."

Along with the hazmat commander and the PROBE developer, the EMS commander also aimed to test PROBE. PROBE had been introduced to the event organizers earlier, and the responders had all been briefed of its purpose and possible importance to future CBRNE event responses. The EMS commander, the hazmat scribe, and all Ops officers had taken part in the PROBE training session the previous day, and were focused on testing it during the simulation. Therefore, all of the responders relied heavily on PROBE for communication and used it at all times during the event. This reliance and importance of testing PROBE is reflected in the communication during the event.

The event could have also been set up to be a media session for PROBE and for the response preparedness, because the simulation was open to the press. Reporters, cameras, and photographers were everywhere, recording the command post, and interviewing event coordinators at the beginning of Phase 1. For that reason, the commanders might have acted more casually for the cameras, accounting for the jokes and socialization that occurred in the command post. Therefore, teamwork in the command post was relaxed, possibly as a result of the presence of the media.

Discussion

There are four sections in the discussion. The summary of findings is provided first. The theoretical implications are presented second, including a discussion on the reconstruction of the transcript, the adequacy of the analysis methods, and the adequacy of the data to analyze communication and teamwork. This is followed by a section on the role of PROBE. The future research section is discussed last.

Summary of Main Findings

The simulation was divided into two phases with respect to two incident action plans. Although it was expected that considerably more planning and communication would occur in Phase 1 as it was the more dangerous of the two phases, the frequency of communication in the command post was fairly similar in Phases 1 and 2.

As expected, the communication analysis revealed that the most frequent types of utterances in both phases were questions, statements, answers, and acknowledgments, both of which enable effective information sharing. Surprisingly, updates, orders, and suggestions were among the least frequent utterance types. These are all crucial in a CBRNE situation, because they enable the accurate planning and playing out of the event response. The analysis in this method also pinpointed 72 instances of ineffective communication in the command post during the entire CBRNE event. To examine the severity of these instances of ineffective communication, content analysis was applied to the data.

The content analysis showed that PROBE, which was of marginal importance to the CBRNE simulation response, accounted for almost half of the communication instances in the command post during the event. Only one instance of ineffective communication resulted in a simulation breakdown, involving the fainting of an EDU police first responder whose oxygen tank prematurely ran out of air. The problem was partly due to the inability of PROBE to forward the second incident action plan as an attachment, and partly to an unexpected change in the level of PPE to be worn into the hot zone after the action plan had been approved. In addition, someone should have been in the warm zone on stand-by, waiting for responders to exit the hot zone, to help them out of the PPE.

Theoretical Implications

Distributed cognition was the theoretical framework guiding the research in this thesis. With this framework, the researcher was able to examine the interactions and exchanges of information between commanders, and between commanders and PROBE. Distributed cognition helped the researcher untangle and understand the communication breakdown which resulted in the fainting of the EDU officer. In fact, this incident occurred partially as a result of an interaction between the Ops officers and PROBE. Had these human-artefact interactions been ignored, the reason for the breakdown may not have been uncovered. Therefore, distributed cognition was a suitable theoretical framework for this thesis.

Cognitive ethnography was used to collect data, guided by the framework of distributed cognition. Cognitive ethnography focuses on detailed observation as the method of data collection. While this data collection method would have been sufficient had the researchers been with the Ops officers, it was not possible to collect enough data to understand the entire simulation response planning process from observations of the commanders. This is because their involvement in the planning was minimal. In the situation described in this thesis, it would have been helpful if the theoretical framework had guided the researchers to go back after the simulation and collect more data via interviews or questionnaire to fill in the 'gaps.' The researchers did actually attempt to contact all the participants after the event, but because these professionals are extremely busy with actual calls, it proved impossible to obtain the additional data that would have helped to accomplish that goal. There is an implicit assumption built into the method, that researchers using cognitive ethnography are experienced. In complex emergency response situations involving several people, equipment, and artifacts, dispersed on a large area of land, it would be helpful for relatively inexperienced researchers to have more guidance for observation strategies than provided by current versions of cognitive ethnography as reported in the literature. Perhaps more experienced researchers would have tackled the situation differently, and would have known what to do to prepare in advance for observing and collecting detailed data. Seen from that perspective, the theoretical framework could be improved by providing more guidance to researchers, including a strategy to help researchers find the correct place to set up in order to observe the right people, ultimately helping them to understand teamwork and communication better.

Reconstructing the event. In the previous event, when the transcript was refined, half of the simulation was not used in data analysis because the second half of the event was relatively inactive in the command post (Lindgaard et al., 2010; Stojmenovic et al., 2011). Therefore, only the data collected in the first half of that simulation were analyzed in detail. One researcher has recommended that only the most important parts of the event should be captured during data collection, to save time transcribing unnecessary material (Williams, 2006). However, in the simulation studied for this thesis, it was essential to collect data throughout the event and transcribe the entire file because the activity levels, mainly communication in the command post, remained stable over the course of the simulation. It is therefore essential to be sensitive to what is happening in a particular situation as well as during the subsequent data analysis, rather than blindly following Williams' (2006) advice only to record parts of a simulation.

Adequacy of analysis methods. At one level, communication analysis and latent inductive content analysis were adequate for the purpose of this thesis. Communication analysis helped the researcher acquire an 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 for this thesis. The analysis of the sequences of codes was essential to identify instances of both effective and ineffective communication in the CBRNE transcript. This added step of analyzing the chronology of utterances enabled the researcher to tie utterances together, thereby seeing clearly which utterances demanding a response, such as questions, were received and responded to. It is argued here 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 instances of open- and closed loop communication. It would be helpful if this process would be recommended in future literature.

Latent inductive content analysis was used to categorize the topic of each utterance enabling the researcher 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 the examination of both types and topics of utterances immediately following the instances of ineffective communication, necessary to reveal the consequences of such communications. This step proved very important in that it allowed the researcher to examine the severity of ineffective communications.

Taken together, the two additional steps in the two analysis methods, one step each, helped the researcher 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 (2010) 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 thesis. However, when analyzing the results of the two analysis methods, it was important to analyze them simultaneously for each utterance. Keeping communication and content analyses separate was thus not necessary. It is therefore suggested that the method applied by Kramer (2010) be used instead.

Inter-rater reliability. The two moderate inter-rater reliability ratings suggest that it would have been helpful if the primary researcher had explained the category definitions and allowed the second researcher to ask questions of clarification instead of only handing her the written category definitions, from Tables 2 and 5. The moderate inter-rater reliability ratings also suggest that the category definitions may have been insufficiently clear to allow the second rater to categorize 10% of the transcript correctly.

Data adequacy to analyze communication and teamwork. The previous study (Lindgaard et al., 2010; Stojmenovic et al., 2011) had two layers of event management: commanders and first responders. The researchers were located in the command post, where all of the action planning took place. The present study had Ops officers as well, whose presence was not announced in advance to the researchers. Once it became clear that the planning of the

CBRNE management response would not take place in the command post, it was too late for the researchers to change locations for observational purposes. Their attendance had not been approved elsewhere; their location was beyond their control; members in the other zones had not signed the informed consent form, and there were only two researchers and insufficient equipment to cover all three Ops locations. The commanders' main function in this event was simply to approve, and amend if necessary, the incident action plans. Thus, frequent updates from the Ops officers were not required, as long as the incident action plan was detailed enough for the commanders to approve it. This misunderstanding with the presence of the Ops officers made data analysis and comprehension of the event difficult as the decision making and teamwork occurred outside of the observed area. Therefore, while the original aim was to understand and comment on teamwork, the situation turned out not to be feasible for that because of the location of the researchers during the CBRNE simulation. Examining teamwork would have been possible if the researchers had been able to be with the Ops officers. Instead, the researcher focused on identifying and interpreting the communication patterns among the people to whom you had access.

One may question the need for three layers of management in the response reported here. The previous event studied covered an entire sports arena in addition to a large area outside of the arena where the command post was set up and all emergency vehicles were parked. By contrast, the present event only spanned about a quarter of that area, and contrary to the previous study in which over 20^{+} actors played 'casualties', no actors were present in this study. Yet, the literature clearly states that three layers of management are typically required in major events (EMOMCSCS, 2008; May, 2009). It is possible that different objectives guided this event, and that, therefore, the management roles deviated from what the literature describes. While the individual teams considered the simulation valuable, as each of them accomplished their goals, the value of the simulation to the researcher who was trying to understand communication and teamwork during the CBRNE event is questionable. Unfortunately, these different goals and objectives did hamper progress towards an understanding of teamwork and communication in this event.

Role of PROBE. Overall, the role played by PROBE in this CBRNE event was supposed to aid communication, supplement decision making, and enable effective teamwork. However, some issues arose as a result of shortcomings because PROBE was still a prototype rather than a fully fledged management 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).

Future Research

In a future study, it would be helpful also to analyze unambiguous nonverbal instances of communication to balance answers, clarifications, attention grants, and acknowledgements with the other communication categories more accurately than was possible here. Audio records do not capture nonverbal behavior. Therefore, future research should also include more video recording and note taking of nonverbal behavior, to help gain a better understanding of communication by acquiring more information on closed loop communication. The video cameras would need to be positioned in front of the people being observed, to capture their facial expressions and some of their gestures. However, in addition to requiring more video equipment, the positioning would be very intrusive to the responders. Therefore, one needs to be sure that the added benefit of having access to the nonverbal communications is justifiable.

In future CBRNE simulations to which researchers are granted access, it would be of benefit for them to know the management structure, the scenario, the magnitude of the event, and the number of professionals expected to take part in it ahead of time. The responders doing most of the planning and management should be the target audience to be observed, as they are most likely in direct contact with the first responders. That is, researchers need to find out more about the simulation and the management structure prior to data collection during the event. Because of the shortcomings associated with insufficient knowledge the researchers had ahead of time of the event analyzed here, a checklist as shown in Table 7 was devised to help future researchers plan and organize their data collection strategies.

Table 7

Data Collection Planning and Organization Checklist

✓	Item	Comments
	What is the name of the simulation?	
	What is the date of the simulation?	
	Who is the contact person for the simulation? (i.e. phone number, email address, etc.)	
	How many people will take part in the simulation?	
	What will the response management structure be? (i.e. commanders, Ops, etc.)	
	Where will each layer of the response be set up?	
	What are the goals of the simulation from these different perspectives:	
	(1) the event organizer(s)	
	(2) the incident commander	

	(3) team leaders/members in the command post (EMS, Police, Hazmat)	
	[illegible]	
	(5) anyone else (e.g. software developer)	
	What agencies will be involved?	
	What are their respective roles?	
	What will the scenario be?	
	Where will the event take place? (i.e. what will the physical environment look like?)	
	How many researchers would you need to cover all intended areas?	
	How much equipment will you need?	
	Is the equipment chronologically synchronized?	
	Are all of the equipment's batteries fully charged?	

Conclusion

CBRNE training simulations are not run very often, and are rarely open to researchers. The opportunity to observe and study such a simulation is valuable to crisis management literature and adds to the understanding of the CBRNE response. It also adds to the understanding of field testing a software prototype, as was the case here with PROBE. Several advantages of a future, fully fledged PROBE were noted. For example, it would enable responders to continue communication even when radios may not be working, and it would also help to create detailed incident reports as team members representing each agency must delivers upon completion of a CBRNE event or simulation. It also provides access to a wide range of CBRNE information sources necessary for successful event management. Most participants had received a one-day training session with PROBE. However, on the day of the event, they had forgotten some of PROBE's features, or perhaps needed more training. A quick review and a pocket-size summary instruction card of the software capabilities could have provided to the responders to remind them of that PROBE's capabilities. These could have reduced the consequences the communication breakdown, involving the fainting of an EDU officer. In addition, this simulation served as a learning experience for the researcher, who learned about the importance of planning for proper data collection. Most of the CBRNE response planning was done by the Ops officers, who the researchers were unable to observe. Using the checklist developed here, it should be possible for researchers better to prepare for observing CBRNE emergency response personnel in a future simulation. This should yield researchers to acquire a better understanding of communication and teamwork.

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Appendix A: Informed Consent Form

Informed consent

The purpose of an informed consent is to ensure that you understand the purpose of the study and the nature of your involvement. The informed consent has to provide sufficient information such that you have the opportunity to determine whether you wish to participate in the study.

Study Title: *Primary Users' Workflow: Investigation of a Crime Scene*

Study Personnel: Dr. Gitte Lindgaard, Ph. (613) 520-2600 # 2255; email: gitte_lindgaard@carleton.ca
Milica Stojmenovic, Ph. (613) 520-2600 #6628; email:

This study has been approved by the ethics committee for psychological research at Carleton University If you have any ethical concerns about this study please contact Dr. Monique Sénéchal (Chair, Dept. of Psychology Ethics Committee), (613) 520-2600 ext.1155, monique_ sénéchal@carleton.ca. For any other concerns, contact Dr. Anne Bowker, (Chair, Department of Psychology, Carleton University, 520-2600, ext. 8218).

Purpose and Task Requirements: This research is being conducted with AMITA Corporation within a CBRNE Research and Technology Initiative (CRTI) funded project (CRTI Project 06-0317TD) to understand your communication needs within the role you would play in the event of a Chemical, Biological, Radiological, Nuclear, or Explosive (CBRNE) event in order to identify potential gaps in your communication with others that could be facilitated by a computer system while managing the event. I would like to follow you around as you perform your activities throughout the simulation exercise today.

Potential Risk and Discomfort: There are no physical or psychological risks involved in this study. If you feel anxious and/or are uncomfortable in any way about your involvement in this study, please bring your concerns to one of the researcher's attention.

Confidentiality: The data collected in this study will be treated with the utmost care and confidentiality. All data are coded such that your name is not associated with your data. Data will be arranged by agency (EMS, Hazmat, Police bomb tech/Police ident). The coded raw data will only be available to the researchers involved in this study. Relevant data will be aggregated to highlight opportunities for the development of software supporting communication between agencies during a CBRNE event. These data will be presented in the form of a report to Amita. With your permission, voice and video recordings will be made for analysis only. No recorded material will be made available to anyone other than researchers.

Right to Withdraw: Your participation in this study is entirely voluntary. At any point during the study, you have the right to not answer certain questions or withdraw from the study without any penalty.

I have read the above description of the Primary Users' Workflow: Investigation of a Crime Scene study and understand the conditions of my participation. My signature indicates that I agree to participate in the study, and this in no way constitutes a waiver of my rights.

Full Name (please print): ______________________________

Participant Signature: ______________________________

Date: ______________________________

Researcher Signature: ______________________________

Date: ______________________________

Appendix B: Instructions

Instructions for people to be shadowed

Good <morning/afternoon>. I am Milica Stojmenovic and I am a master's degree student from Carleton University in Ottawa. I understand that <name of person who approached the participant> has asked if you were willing to participate in the study by allowing us to follow you around and observe your actions during this simulation exercise. Our purpose is to try to identify any communication needs you may have in the role you play during the exercise so as to understand how your activities could be better supported by interactive technology. We are especially interested to understand needs that are unfulfilled with the equipment you have at the moment. Are you still comfortable with participating? <if no, thank them and report back to the person in charge for another contact. If yes> Great! Thank you very much. Before we start, I would ask you to read and sign this informed consent form, please.

Do you have any questions at this point?

Appendix C: Debriefing Form for Observations

Debriefing

Thank you very much for giving us your time and for sharing your knowledge today. The information you have given us and the activities we have been allowed to observe are a great help in our efforts to understand the communication needs of someone playing the role you played in the exercise today. All the observations made today will be aggregated to provide a clearer picture of how a computer system might facilitate communication among the combined efforts of the different agencies that took part in the simulation exercise.

If something should be unclear once we begin to analyze the data, would you mind if we were to call you again for clarification, please?

If you would like more information about this study, please contact Dr. Gitte Lindgaard in the Department of Psychology at Carleton University (613) 520-2600 ext. 2255(gitte_lindgaard@carleton.ca).

If you would like more information about your rights as a participant, or if you have any concerns about the study, please contact Dr. Monique Sénéchal (Chair, Dept. of Psychology Ethics Committee), (613) 520-2600 ext.1155, monique_sénéchal@carleton.ca. For any other concerns, contact Dr. Anne Bowker, (Chair, Department of Psychology, Carleton University, 520-2600, ext. 8218).

If you think of anything that should be mentioned and that was not raised in the interview, please do not hesitate to contact me (e-mail:).

Thank you again for participating.

Appendix D: The frequency an individual spoke during the CBRNE simulation

Overview of the CBRNE simulation communication

This section describes the communication that occurred during the CBRNE simulation, with respect to the speaker of the communication. Further analysis, including a social network analysis of the data can be found in Stojmenovic (2011). Table 8 shows the number of times an individual spoke during the CBRNE simulation. The leftmost column shows the speaker of a communication. The middle two columns show the frequency with which the speaker communicated in Phase 1 and Phase 2 of the simulation. The last column in Table 8 shows the overall frequency of communication, throughout the entire CBRNE event.

Table 8

The frequency an individual spoke during the CBRNE simulation

	Frequency of Utterances		
Speaker	Phase 1	Phase 2	Total
Incident Commander	**143**	**159**	**302**
Police Ops	15	28	43
Police First Responders	0	4	4
Police Scribe	68	66	134
Hazmat Commander	**248**	**175**	**423**
Hazmat Ops	31	40	71
Hazmat First Responders	1	14	15
Hazmat Scribe	109	49	158
EMS Commander	**150**	**135**	**285**
EMS Ops	13	34	47
EMS First Responders	8	9	17
Event Manager 1	11	23	34
PROBE Developer	83	93	176
Event Manager 2	23	30	53

In general, the communication volume between Phase 1 and 2 was fairly similar, as seen in Table 8. This was surprising because the chemical was neutralized, victims were found and removed from the hot zone, and the bomb was deactivated in Phase 1. In other words, the most dangerous parts of the CBRNE event were dealt with in the Phase 1, which should have warranted a high frequency of communication, allowing commanders to organize the response. This should have accounted for the majority of communications, leaving little need for activity in Phase 2. However, as seen in Table 2, this was not the case, as the commanders were more involved in planning and altering the second incident action plan for re-entry into the hot zone for cleanup and evidence collection than they were for the first incident action plan.

Since the first biohazard found was a chemical, the hazmat commander was the most active person in the entire simulation. Therefore, it is not surprising that the hazmat team was the most active response agency overall. In Phase 1, the fire and hazmat department communicated on 389 occasions. Similarly, in Phase 2, their total number of instances of communication equal to 278. Interestingly, the hazmat commander also did not give instructions on how to neutralize the chemical offending agent.

The EMS commander was the least active of the three commanders. Perhaps this occurred because there were only three 'victims', presented in the form of pie plates with symptoms written on them, which did not require a lot of attention. Correspondingly, the least active agency in Phase 1, was the EMS department, with a total number of instances of communication of 171. Similarly, in Phase 2, the least active agency was the EMS department, with a total number of instances of communication in that Phase equal to 178. Since the 'casualties' were pie plates, the EMS first responders duties were limited to monitor the vital signs of teammates going in and coming from the hot zone - a routine task for paramedics, not requiring a lot of communication. However, these frequencies of communication involve the scribes' communication levels. If the scribes are not counted, and only the frequency of communication captured by the researchers of Ops and first responders, then the EMS team members spoke more frequently than the hazmat team. Although, these communications were largely not captured by the researchers. Therefore, communication and teamwork cannot be conclusively determined about the teams in the warm and hot zones.

The least frequent speakers are the three groups of first responders, closely followed by the Ops officers, event coordinators, and PROBE developer. This finding is a reflection of the communication chain of command because the researchers were located in the command post, the members of which only spoke to each other, and to their corresponding Ops officers. The researchers' attendance was cleared in the command post ahead of time, unknowing that the management structure would involve Ops, as this was different from the previous study. It was too late to request access to Ops and first responders during the incident. Therefore, conversations involving Ops officers and first responders were largely not captured and thus could not be included in the analysis. The PROBE developer spent a lot of time in the command post, helping the scribes and the EMS commander use the system, and solving glitches as they occurred.

In summary, the most communicative commander was the hazmat commander, followed by the IC, and EMS commander. Their agencies' communication and activity levels cannot be determined due to lack of data. In addition, a simple summary of who spoke how many times does not give an understanding of the communication that happened during the CBRNE simulation. Therefore, in order to get a better understanding of communication, and ultimately communication breakdowns and teamwork, communication and latent content analyses were applied to the data.

Appendix E: Communication analysis types of utterances in Phase 1

In the following table, 'IC' represents the incident commander, 'Pop' represents the police Ops officer, and 'PFR' represents the police first responders. 'HCo' represents the hazmat commander, 'Hop' represents the hazmat Ops officer, and 'HFR' represents the hazmat first responders. 'ECo' represents the EMS commander, 'Eop' represents the EMS Ops officer, and 'EFR' represents the EMS first responders. Additionally, 'L' and 'I' are the CBRNE simulation event coordinators. 'P' represents the software developer on-site for PROBE.

	Speaker														
Utterance Type	IC	Pop	PFR	Psc	HCo	Hop	HFR	Hsc	ECo	Eop	EFR	L	P	I	Total
Acknowledgment	24	1	0	5	44	6	0	9	21	3	0	1	14	1	129
Answer	15	2	0	7	30	4	0	36	35	4	0	1	22	6	162
AttentGranting	4	1	0	0	4	7	0	0	8	4	0	0	1	1	30
AttentRequest	4	4	0	0	12	4	1	0	6	1	5	0	1	0	38
ClarifGranting	3	1	0	2	6	1	0	4	0	0	0	2	0	1	20
ClarifiRequest	2	0	0	1	9	0	0	3	6	0	0	0	2	2	25
Complaint	14	0	0	2	9	0	0	0	10	0	0	0	2	1	38
Explanation	5	0	0	5	22	0	0	10	12	0	0	2	16	2	74
Joke	3	0	0	0	5	1	0	1	5	0	0	0	2	1	18
Order	4	0	0	0	7	1	0	1	4	0	0	3	1	0	21
Question	37	0	0	25	63	1	0	11	29	0	0	0	14	5	185
Repeating	14	0	0	0	15	0	0	1	2	0	0	0	0	0	32
Statement	27	2	0	17	44	2	0	33	31	0	0	2	17	3	178
Suggestion	2	0	0	1	3	0	0	3	0	0	0	0	3	0	12
Update	1	4	0	2	4	4	0	0	5	1	3	1	1	0	26
Total	159	15	0	67	277	31	1	112	174	13	8	12	96	23	988

Appendix F: Communication analysis types of utterances in Phase 2

In the following table, 'IC' represents the incident commander, 'Pop' represents the police Ops officer, and 'PFR' represents the police first responders. 'HCo' represents the hazmat commander, 'Hop' represents the hazmat Ops officer, and 'HFR' represents the hazmat first responders. 'ECo' represents the EMS commander, 'Eop' represents the EMS Ops officer, and 'EFR' represents the EMS first responders. Additionally, 'L' and 'I' are the CBRNE simulation event coordinators. 'P' represents the software developer on-site for PROBE.

	Speaker														
Utterance Type	IC	Pop	PFR	Psc	FCo	Hop	HFR	Hsc	ECo	Eop	EFR	L	P	I	Total
Acknowledgment	28	8	0	8	45	6	4	7	24	9	2	3	17	4	165
Answer	17	4	0	13	29	5	1	9	11	7	0	7	20	9	132
AttentGrant	6	4	0	0	4	4	5	0	4	8	1	1	2	0	39
AttentReq	6	8	2	1	14	10	2	0	6	5	2	0	0	0	56
ClarGrant	7	0	0	4	4	0	0	1	5	0	0	0	1	0	22
ClarReq	4	0	0	3	4	0	0	3	4	0	0	0	1	5	24
Complaint	0	0	0	1	0	0	0	4	14	0	0	0	0	0	19
Explanation	9	2	0	4	6	1	0	5	10	1	0	6	15	4	63
Joke	6	0	0	4	7	1	0	1	1	0	0	0	1	1	22
Order	5	0	1	0	3	0	1	0	2	0	0	1	1	0	14
Question	46	0	0	18	38	1	0	6	32	0	0	3	13	1	158
Repeating	8	0	0	2	4	2	0	1	7	0	1	0	0	0	25
Statement	27	0	0	10	20	2	0	11	18	1	0	1	23	7	120
Suggestion	3	0	0	0	3	1	0	0	2	0	0	1	1	0	11
Update	3	7	1	2	1	9	2	2	2	5	3	1	0	1	39
Total	175	33	4	70	182	42	15	50	142	36	9	24	95	32	909

Appendix G: Latent inductive content analysis category totals from Phase 1 of the CBRNE event

In the following table, 'IC' represents the incident commander, 'Pop' represents the police Ops officer, and 'PFR' represents the police first responders. 'HCo' represents the hazmat commander, 'Hop' represents the hazmat Ops officer, and 'HFR' represents the hazmat first responders. 'ECo' represents the EMS commander, 'Eop' represents the EMS Ops officer, and 'EFR' represents the EMS first responders. Additionally, 'L' and 'I' are the CBRNE simulation event coordinators. 'P' represents the software developer on-site for PROBE.

			Topic					
Speaker	ActPlan	Communication	Equipment	Event	OffAgent	Personnel	PROBE	Total
IC	30	9	6	7	9	21	64	146
Pop	4	0	3	0	2	0	2	11
PFR	0	0	0	0	0	0	0	0
Psc	2	1	0	0	0	1	62	66
HCo	35	7	15	24	25	33	109	248
Hop	6	0	1	5	2	2	2	18
HFR	0	0	0	0	0	0	0	0
Hsc	1	1	4	2	12	0	87	107
ECo	19	5	13	2	6	19	84	148
Eops	3	2	3	0	0	0	2	10
EFR	3	0	0	0	0	0	0	3
L	1	0	7	2	0	2	0	12
P	1	0	1	3	0	6	71	82
I	2	0	0	2	2	8	4	18
Total	107	25	53	47	58	92	487	869

Appendix H: Latent inductive content analysis category totals from Phase 2 of the CBRNE event

In the following table, 'IC' represents the incident commander, 'Pop' represents the police Ops officer, and 'PFR' represents the police first responders. 'HCo' represents the hazmat commander, 'Hop' represents the hazmat Ops officer, and 'HFR' represents the hazmat first responders. 'ECo' represents the EMS commander, 'Eop' represents the EMS Ops officer, and 'EFR' represents the EMS first responders. Additionally, 'L' and 'I' are the CBRNE simulation event coordinators. 'P' represents the software developer on-site for PROBE.

	Topic							
Speaker	ActiPlan	Comm	Equip	Event	OffAgent	Personnel	PROBE	Total
IC	52	16	7	25	6	19	27	152
Pop	15	0	0	2	0	1	0	18
PFR	2	0	0	0	0	0	0	2
Psc	2	1	1	0	0	1	59	64
HCo	29	15	20	36	5	18	38	161
Hop	12	1	4	1	2	3	3	26
HFR	4	0	1	0	1	1	0	7
Hsc	3	2	2	0	2	3	40	52
ECo	13	11	13	7	0	17	62	123
Eop	12	1	4	0	0	2	2	21
EFR	4	0	1	0	0	1	0	6
L	1	2	0	19	0	0	0	22
P	0	0	0	5	0	1	85	91
I	12	5	9	0	1	1	0	28
Total	161	54	62	95	17	68	316	773