Designing Technology for Shared Communication and Awareness in Wilderness Search and Rescue

Brennan Jones[1,2], Anthony Tang[3], Carman Neustaedter[2], Alissa N. Antle[2], and Elgin-Skye McLaren[2]

1: Department of Computer Science, University of Calgary

2: School of Interactive Arts and Technology, Simon Fraser University

3: Faculty of Information, University of Toronto

Abstract:

Wilderness search and rescue (WSAR) is a carefully planned and organized team operation, requiring collaboration and information sharing between many volunteers who are spread out across various locations in the outdoors. Workers play a variety of roles, both on the ground and at a command post, and they need information and awareness specific to those roles. In our work, we are interested in understanding how this information is gathered and passed around, how it helps WSAR workers achieve their goals, and what challenges they face in sending and receiving information as well as in maintaining proper awareness. We conducted a study where we interviewed WSAR workers and observed a simulated search. Our findings reveal that WSAR workers face challenges in maintaining a shared mental model when radio and network connectivity are sparse. Our insights reveal opportunities for new communication modalities, such as (but not limited to) video communication, augmented reality, drones, and team-collaboration platforms to provide awareness and make communication and coordination easier remotely across various locations, but particularly between the field teams and Command workers. However, such technologies should also be designed to anticipate gaps in radio reception, and provide opportunities for workers to communicate asynchronously and see relevant 'offline' information in a context-dependent manner. We present design ideas that pursue some of these opportunities.

Introduction

When a hiker gets lost in the woods or a skier does not return home from the mountain, a search crew needs to be called to find the missing person and bring them out of the wilderness safely. Wilderness search and rescue (wilderness SAR, or WSAR) is time critical, in that personnel need to find the missing person (called the *subject* of the search) as soon as possible, as surviving in the wilderness for a long period of time is incredibly difficult, especially for someone who may be injured. In many parts of the Western world, WSAR groups are volunteer based, though volunteers are professionally trained, and their training is consistent among members. As a result, they have a shared understanding of work protocols and language. However, each member also has a unique set of skills and a unique perspective to provide to the operation. For example, some are managers with a higher-level overview perspective, while others are ground workers with a lower-level and more-focused perspective.

Figure 1: WSAR involves careful communication, coordination, and information sharing between managers at a command post (left) and searchers in the field (right).

In a typical scenario in Western Canada (which is similar to other parts of the world), a SAR agency would be called to respond to a report of a missing person [23,24], herein called the *subject* of the search. The *SAR manager* on duty for the agency would respond and send a callout to available members of the agency to meet at a staging area, which is usually set by the manager to be a convenient location near the search area. As members arrive, they form one or more *field teams* who are given assignments to search specific areas of the field using different search techniques. The manager and her management team (herein called *Command* for simplicity) set up a mobile-office, which is usually a trailer or set of trailers, at the staging area in advance of the members' arrivals (Figure 1, left). This is the base location where Command works; coordinating and keeping track of teams and equipment, overseeing the operation, and making planning decisions. As field teams search their assigned areas (Figure 1, right), they report back important information (e.g., clues found, environmental hazards that could pose a threat to other teams, etc.) to Command. Many SAR agencies in Western countries work on a collaboration basis, where teams will call for assistance from other teams in the event that a missing person is not found within a few hours, or in the case where stakes are high; e.g., there are multiple missing people, or the weather is severe and they need to find the missing person as soon as possible [23,24].

WSAR teams look for and rescue lost people in *wilderness* areas, which are natural areas on land not built up with a lot of infrastructure. Besides a hiking trail and a few sign posts, the majority of the area is untouched nature. Often, these areas contain dense forests, rivers, lakes, mountains, valleys, and wildlife. This is in contrast to urban SAR, which takes place in urban areas and collapsed buildings, usually after a disaster; marine SAR, which takes place in the open sea and other large bodies of water such as the Great Lakes, usually for lost vessels such as ships and crashed airplanes; and, combat SAR, which is the search for and extraction of people from war and conflict zones.

For our work, we are interested in understanding what challenges WSAR workers face in remote communication and distributed collaboration, and exploring how newer collaboration technologies such as augmented reality, video communication, drones, and shared digital workspaces could help address some of those challenges. In WSAR, there is a lot of information sharing between managers at Command and workers in the field. This information is used to keep Command aware of the statuses and activities of field teams, and to aid in planning the future actions of the responding agency as a whole. We are interested in understanding how this communication and information sharing happen, what goals they support, and how we can design newer technologies to better support this information sharing so that they aid WSAR workers in maintaining the situation awareness [13] and team cognition [15,19] they need. We have been working closely with WSAR groups in Western Canada for this purpose.

Past and ongoing research has explored how to design and build collaboration technologies for other emergency-response and high-stakes situations such as firefighting [25,33,34] and disaster response [1,2,4,8,9,30,35]. We can learn from some of the insights of this work and apply it to WSAR contexts. For example, WSAR shares some similarities with firefighting in that there are many workers 'on the ground' responding to an emergency, communicating and coordinating with each other, and answering to a commander [33]. Roles are highly structured, usually in accordance to a standard protocol such as the *Incident Command System* (ICS) [7,17,37], and information typically flows between personnel based on their roles, responsibilities, and positions within the pre-defined hierarchy. It also shares some similarities with disaster response [29,30,36], in that response efforts happen over longer periods of time, and commanders make use of information from multiple distributed sources 'on the ground'.

Implicit communication (sometimes called *consequential communication*) happens when a message is sent or received that is not *intended* to be communication.

It is unintentional communication that happens as a result of one's use of or interactions with a tool or artifact [14]. For example, someone putting on their jacket and hiking boots communicates that that person is about to go outside and on a hike. The act of putting on the jacket and boots is not intended to be a communicative act, but it still communicates a message. This is in contrast to *explicit communication*, which is when an act is solely a communicative act, intended to be interpreted as communication [14]. Implicit communication is usually done through non-verbal actions, whereas explicit communication can happen through both verbal words and non-verbal actions. Both implicit and explicit communication are important for team emergency-response situations such as firefighting [16,33] and avalanche rescue [11].

In addition to the insights that work on other emergency situations provides, we must also take into account some factors that make WSAR unique. For example, compared to urban firefighting contexts, WSAR workers operate for longer periods of time on average, and in remote wilderness environments with unpredictable terrain and weather. Teams are scattered across distances and isolated from most of their colleagues, aside from those on their field team. This reduces opportunities for face-to-face interactions with others, and particularly with managers and planners at Command. With this being the case, remote communication is heavily emphasized. Field teams need information and instructions from Command, and Command needs information from the field. A great deal of information is passed along remotely, which brings about challenges in properly transmitting, receiving, and handling this information so that it is made the best use of.

Furthermore, because WSAR takes place in natural areas with little built-up infrastructure, the search areas often contain poor cellular coverage. Additionally, geographic features such as mountains and valleys can block radio signals, resulting in radio 'dead zones' and in situations in which field teams transition between varying states of connectivity to other teams and to Command. This creates a lack of reliable realtime communications between all members of a responding agency, thus making it harder to maintain a *shared mental model*. A shared mental model is a shared awareness, understanding, and agreement, of the progress made in the operation and the status of teams, workers, and equipment; and the ability to project that knowledge to understand what will happen next and make future plans [6].

We focus our work on addressing the following research problems:

(1) What types of information do WSAR workers pass along to each other remotely? Who passes along this information? To whom is it sent to? And what purposes do remote communication and information sharing fulfill in WSAR?
(2) What challenges do WSAR workers face in sending and receiving information remotely? What challenges do they face in understanding and making good use of information that is passed along remotely?
(3) How can we design technologies that better support remote communication and information sharing in WSAR?

In this chapter, we discuss an investigative study we conducted to understand WSAR communication and collaboration contexts and challenges. We also discuss technology prototypes we designed that present solutions to some of the challenges raised in our study.

Investigative Study

Our first goal was to understand the communicative and collaborative needs of WSAR workers and teams, the challenges that they face in remote communication, distributed collaboration, and maintaining a shared mental model, as well as the design opportunities and recommendations for distributed-collaboration tools for WSAR. In order to do this, we conducted an investigative study [21] consisting of two components: (1) an *interview* component, and (2) an *observation* component.

For the first component, we interviewed 13 WSAR workers (11 men and two women), including four managers and five field team leaders. Interviews were each at least one-hour long and conducted in-person, over the phone, or via Skype, depending on the participant's preference and availability. We recruited participants from volunteer SAR agencies in Western Canada, serving communities near mountains, lakes, rivers, and forests. Our participants were between the ages of 32 and 65 (M = 49, SD = 13), and had between four and 21 years of experience working in WSAR (M = 10, SD = 7). Though we aimed for as much diversity in our participants as possible, the gender imbalance of our participants stems from the fact that, in Canada at least, there are more men serving as WSAR volunteers than women.

For the second component, we observed a mock WSAR activity where over 100 volunteers from 14 local SAR agencies gathered to search for 15 fictional lost subjects in a forested area surrounded by mountains. This operation lasted for a full day and was organized by a local SAR agency for training purposes. The event simulated the entire experience of a normal WSAR operation from beginning to end, including setting up the command post on site and organizing search assignment and sending out field teams. Only the organizers, who were not actually involved in the mock search as participants, knew all of the details of the simulation. Thus, none of the actual participants in the simulation knew all of the details beyond what they would learn on their own through carrying out the operation. A researcher on our team observed the operation from the command post, as a fly on the wall, took detailed notes, and asked contextual questions to volunteers whenever they had a free moment. Due to safety and liability concerns of the organizers, we were unable to get a researcher to observe from the field perspective.

We used open, axial, and selective coding to analyze the interview and observation data and reveal higher-level themes. We looked at phenomena from the perspectives of both the field and Command, to understand the similarities, differences, and tensions between the two settings. Open codes included things such as *sending information*, *receiving information*, *location awareness*, and *activity awareness*, while axial codes included categorizations of the open codes such as *information sharing* and *awareness*. Selective codes and themes included *communication goals*, *communication challenges*, and *workarounds*.

Next, we present an overview of our findings, followed by a set of design opportunities for WSAR remote-collaboration technologies. We then present design ideas following those opportunities and make suggestions for future work in this area.

Findings and Design Opportunities

Distributed Cognition and Awareness

Workers at Command have many opportunities for implicit communication and awareness, given that they are co-located. Their interactions with each other are similar to those found in settings such as emergency coordination centres [3] and other control rooms [18,27,28]. In particular, workers communicate both explicitly and implicitly. We observed that managers made great use of written forms and physical artifacts, as well as their positions in the command office (Figure 2), in maintaining a mental model of the status of the operation. They used these artifacts for record keeping, planning future actions, and maintaining awareness of the progress of the search, including the statuses of personnel and resources. In accordance with distributed cognition, they offloaded this knowledge into the artifacts spread out across the command vehicle, thus making it easier for the management team to maintain a shared mental model of the operation. This was especially useful during role changeovers, which can happen during larger searches spanning several days.

Figure 2: The inside of the mobile office at the command post, where the SAR management team oversee the operation, make planning decisions, and coordinate field teams.

We observed that managers at Command communicate explicitly through talking directly to each other, and implicitly through keeping notes on paper and whiteboards, passing paper notes, clustering forms in various locations on the wall, displaying maps and progress information on large screens, and playing back incoming radio messages on the speaker so that everyone in the command post can hear them. The shared artifacts at Command, such as the forms, sticky notes, and digital information on screens, acted not only as artifacts for offloading knowledge (as per distributed cognition), but also as mediums for communication; i.e. *feedthrough* artifacts (see [12]). In other words, we observed managers at Command making use of these artifacts, pointing at forms, referencing locations on maps, and passing sticky notes, to support their communication with each other. The artifacts at Command also act as knowledge containers, conveying and keep track of people's roles, tasks, team assignments, availability of equipment, and search areas that have been covered, and so on so forth. Workers wear different-coloured vests indicating their roles. These vests act both as communication artifacts (i.e., 'I am wearing a *Planner* vest, therefore I am a *Planner*') and artifacts storing knowledge (i.e., 'the *Planner* vest is located on this person, thus she is the *Planner*'). At Command, it is generally easy for someone to get the information they need simply by paying attention to their surroundings or by looking through artifacts and notes around the command vehicle. Workers can quickly figure out one's status through this implicit communication. Though when it comes down to understanding the situations of field teams, given that they are far from the command post, management is more-heavily reliant on the artifacts at Command, since they cannot directly observe the field teams.

During the mock search, when Command deployed field teams, they gave them each a set of paper maps and forms with the subject description, as well as notes on what type of search to conduct and where to search. Field teams would then take these forms out to the field with them and use the information on them for their duties. Both the field team and Command had a photocopy of the same forms. Command placed their copies of the forms on the wall in the command vehicle, to keep track of who was in the field and what they were doing. Each field team carried a GPS device and walkie talkie with them in the field, which they used to communicate with Command. When a team returns, they would debrief with Command. It was at this stage that they would share in-person any information that had not been shared yet, or discuss in-detail information that could not have been shared easily over the radio. They would make references to their GPS records and locations they 'starred' or 'pinned' using their GPS devices when discussing what they found. They would also return their copies of the forms to Command, where they would then be paired with Command's copies and moved to a special section of the wall containing the completed task assignments.

While implicit communication through *feedthrough* and *deictic referencing* [12] between Command and a field team was easy when the team was at Command (either before or after an assignment), it was non-existent during an assignment, when a team was out in the field. Field teams could refer to annotated maps and notes from Command when out in the field, but when communicating via the radio, they could not make deictic references to their surroundings (e.g., *'Look over here!'*) or use objects as mediums for communication with Command. Instead, field teams had to be very descriptive when describing their surroundings or asking for help, as they had to be sure Command understood everything as much as possible. We noticed that sometimes teams even have to repeat their messages or reword them in order to get Command to understand them, and even then misunderstandings would still occur.

We observed that the management team logged all radio messages from the field carefully and with a lot of detail. They did this to have a time record of key events to be able to refer to later if needed, and to protect themselves for liability purposes. In accordance with distributed cognition, the knowledge contained in the radio messages were transferred to the communications log, and thus was contained in the workspace and belonged to the organization as a whole. The knowledge could be used by others in the organization at a later time.

In contrast to the management team, who had an awareness of the bigger picture, field teams had a more-focused lower-level picture of things, in relation to their current task assignments. According to some SAR workers, this level of detail was usually enough to complete their duties.

Though field teams are expected to stay focused on their tasks, we were told that sometimes they deviate from their assignments for various reasons. The overarching reason is usually that teams have a perspective from the field that is different from that of Command. They can see and experience things first hand that Command cannot from their mobile office. Thus, they may be making decisions based more on what they are experiencing first hand and less on what Command is suggesting to them. The realities of what is in the field may be different from what Command assumed the situation to be in the field. For example, a path that Command asked the team to search along might not exist or might be unsafe to traverse.

Consistency and Control

WSAR workers used documentation and communications to maintain a shared mental model and consistent agreement and understanding of what was happening, what progress was made, and what everyone is supposed to be doing. Command wanted workers' knowledge to be as symmetrical as possible, and did not want there to be serious discrepancies in workers' knowledge or in what they are doing versus what Command expects them to be doing.

We observed that managers at Command maintain radio communications with field teams to build a higher-level situation awareness and shared mental model of the current status and progress of the search. They need this awareness for four main reasons: (1) to ensure that the teams in the field are safe, (2) to make sure they are on the right track in their assigned duties, (3) to understand the challenges they are facing, and (4) to prompt them for information and updates from the field (e.g., on clues they have found) in order to make informed decisions on what actions to take next. Command wanted new information to keep flowing in from the field so that their mental model would continue to update. Furthermore, Command wanted to keep in touch with field teams in order to update them with new information that was relevant to them, thus updating their mental models to the extent necessary, and keeping workers' knowledge consistent and symmetrical.

Network Sparseness

One challenge our participants raised though was that radio reception is usually unreliable in the wilderness. This leads to incomplete information and asymmetries in knowledge, which makes it more difficult for WSAR responders to maintain a shared mental model. Some teams experience complete radio silence, or are in a state of being 'offline' from communications, often for several hours, which results in gaps and delays in information transmission. Command may not receive new information from a field team for several hours, and this information may be out of date by the time they receive it. Similarly, a team that is in a radio gap may not hear updates about the bigger picture of the operation until they return to Command or step back into radio range. This contributes to asymmetries in workers' knowledge and their individual mental models. In some extreme cases, this could mean a team continues to search their assigned area for hours after the subject is found.

Furthermore, radio gaps sometimes resulted in a field team being in a 'partially-offline' state, in which they are able to hear the radio transmissions of some teams but not of other teams. Hearing parts of a conversation made it difficult for teams to put it into context, as there was missing information. The 'severity' of 'online/offline' state depends not only on how many others the team is able to contact, but more so on *whom* they are able to contact. For example, not being able to contact Command may be worse than not being able to contact another field team that is searching a location several kilometres away.

Prioritizing Communication

Different types of information need to be sent back and forth between Command and the field. Though they all need to go through, they have different levels of priority. Regardless of this, our findings reveal that the two-way radios that WSAR workers use do not always make it easy to convey the priority of messages.

For one, all radio messages were sent and received in the same way, regardless of priority. Some messages were high priority and needed to be responded to immediately (e.g., a field worker was injured and needed medical attention), while others were less urgent (e.g., a field team was giving a routine update to Command on their current location and progress in their task). However, two-way radios treat all messages the same (in a technological sense, at least), making it more difficult to distinguish between high-priority and low-priority messages. This introduced the potential for the recipient to not understand the true priority of the message. Workers had to resort to using verbal terms to convey the urgency of messages, such as *"pan-pan"* (i.e., the situation is urgent but not life-threatening) or *"mayday-mayday"* (i.e., the maximum urgency level; the situation is life-threatening).

In addition, all messages required the same amount of work to attend to, regardless of their priority. Field workers said that they often have to stop what they are doing and find a location where they have radio connectivity with Command in order to send a message; rather than being able to queue up less-important messages to be sent as a text later. Command has to listen to and respond to messages at the moment they come in; rather than having less important messages arrive in an inbox and being able to attend to them at a more convenient time.

In other cases, field teams wait until they return to Command before giving them some less-crucial piece of information, in order to avoid cluttering the radio with mundane messages. This is effectively asynchronous communication. As an example, we observed that when a team returns to Command, they would give a SAR manager their GPS device, containing a record of all the locations they traversed in their assignment. The manager would then upload the GPS record to a computer that would then display the path overlaid on a map. Over time, this digital map would populate with all of the paths of teams' completed search assignments, as well as pins indicating special locations highlighted by teams as 'points of interest'. This digital map would act as a representation of the status and progress of the search, as well as a of the organization's collective knowledge and shared mental model. This also gave field teams an opportunity to explain, in-person, what they found in the field. This was easier to do when the team was back at the command post, rather than while in the field in the midst of their assignment. The lack of clarity of some messages over the radio, the difficulty of using the radio while trudging through the wilderness, and radio reception gaps made it more feasible to share this larger amount of information at Command, after it had already been logged automatically by a device.

Awareness in the Field

Field workers have told us that they want to have some awareness of other teams' activities and the bigger picture of the operation, even when they are focused on their specific duties. They want to know, to the extent that it is relevant to them, how the bigger picture is evolving, what their impact is on the search operation, and how their remote team members are doing. Given that teams tend to spend hours in the wilderness, at the very least this awareness could boost their morale and make them feel less isolated from the rest of the organization.

While this is the case, field teams generally benefit from a narrower scope of awareness, according to SAR managers, as they are supposed to be focused on their own duties. This creates an important design tension. High focus and structure is important, though some awareness of the bigger picture and how one's actions fit within it could boost motivation and morale. This is similar to how players of online video games feel a higher sense of team commitment when they are able to hear and communicate with their team members [10]. Field workers sometimes try to gain this awareness by eavesdropping on communications between other field teams and Command on the radio channel. There is always an inherent curiosity of what others are doing and what they have found in the field. Sometimes this awareness can be useful, in that they could overhear relevant information from nearby teams, and potentially coordinate based on that. For example, if a Team A discovers an obstacle and tells Command about it on the radio, Team B nearby could overhear that message and adjust their actions based on that nearby obstacle; and potentially talk to Command or Team A directly about it. While it could have some benefit, hearing too much side communication can distract workers from focusing on their work and listening/watching for the subject.

While teams can overhear a lot of radio communications between the field and Command, they are generally prohibited (with some exceptions) from communicating directly with each other on the radio without permission from Command. There are two reasons for this: (1) Command wants to prevent the radio channel from having too much traffic, since they need to listen to and record all communications on the shared channel, and (2) Command wants to have control and awareness of communications. Usually when Command grants permission for two teams to talk directly to each other, it is for nearby teams that need to coordinate actions or resources in the field directly, without the inefficiency of having to go through Command first. For example, two nearby teams may need to talk to each other to help each other navigate around obstacles. In these types of cases, communication is quicker and more efficient if it is more direct, and the teams need to coordinate to get something done together as quickly and efficiently as possible.

Use of Alternative Remote-Communication Modalities

While the radio is useful for certain communications, there are other times when workers may want to send information through other channels beyond just audio. For instance, visuals and information rich in detail may be difficult or time-consuming to describe verbally, and in some cases it may be helpful to send a photograph or video. Some SAR agencies already do this; allowing their members to send photos and videos of clues, as well as text descriptions, via SMS/MMS messaging to a manager at Command.

The main challenge with introducing multiple communication modalities though, according to SAR managers, is that it could make it more difficult for Command to build a bigger-picture understanding of what is happening, as they then have to pay attention to multiple streams of information. In addition, it also adds a cost, as workers have to then be trained in how to properly utilize new communication channels (e.g., they may need to learn how to send an effective video message). This suggest two things: (1) it may be more beneficial to aggregate existing communication channels and information streams before introducing new ones, and (2) WSAR workers and agencies should carefully consider whether or not a new information stream is actually necessary before adding it, as there could be a cost overhead of adding it (it is something else that has to be paid attention to).

Summary, Design Opportunities, and Recommendations

The findings from this study demonstrate that while maintaining a shared mental model is important for a WSAR response, there are many aspects of WSAR that make this challenging. We highlight the following design opportunities:

[Design Opportunity #1] *Technology can be designed to support a shared mental model amongst WSAR workers responding to an incident.*

During a search, most communication happens on a single radio channel. This has the unintended side effect of keeping everyone in the loop, and aware at a higher level of what is happening, thus helping to foster a sense of inclusivity, team work, and purpose for one's work. Beyond overhearing radio communications, there are potentially other opportunities for technology design to foster this sense of belonging to a team. For example, technology that allows field workers to see the areas they have covered, the areas their colleagues have covered, and a collection of clues their colleagues have found as well as the messages they have sent (e.g., as text snippets) would allow them to see their actions and contributions in relation to their team mates, and this could foster a sense of community.

[Design Opportunity #2] *Gaps in radio and cellular reception bring about unique challenges in maintaining shared mental models across scattered locations, and so there is a necessity to support building and maintaining a shared mental model in network-sparse situations.*

While there are some technological solutions, like radio repeaters and mesh-networking technologies (e.g., [38]) that could help minimize disconnectedness between teams and Command, more could still be done to provide WSAR workers with relevant information and awareness and maintain a shared mental model while disconnected. For example, it could be valuable to explore technologies that present field workers with relevant 'offline' information; or in other words, information that is *already there*, that can be presented to the user at relevant times while out of radio contact, or while 'offline'. To illustrate a simple example: technology could show a field team how much of their assigned area they have covered, or show Command a prediction (through a statistical model) of where out-of-contact teams may be located and how much progress they are likely to have made at the current time, based on information that is already known, such as their given task assignments, their last-known position, weather, etc. While the information may not be perfectly accurate (e.g., it may be out of date or 'stale'), it could still provide users with more to work with than just seeing nothing. Another example: when field workers are 'offline', technology could give them relevant information such as expected weather changes, predictions of where the other field teams are located, and predictions of when Command might want to receive an update from them.

[Design Opportunity #3] *There could be benefit to introducing increased awareness between field teams and Command.*

This already exists to some extent, as Command is able to observe the GPS locations of teams, look at forms, and listen in on radio conversations. Even with all of this though, Command still needs to put a lot of effort into communicating explicitly with the field teams to get an update of their statuses. There could be benefit to having more of this information come in automatically. It could save time for Command, allowing them to put more attention toward other activities. For example, it may be worth exploring wearable 360° cameras worn by field workers that automatically take and send geotagged photos of their surroundings to Command, where they are then displayed over maps of the search area. Photos could come in periodically (e.g., every 10 minutes, or every 500 metres) or during key events such as when they have reached a certain location or when they are stopped for a long time.

In addition to these opportunities, we also make the following recommendations:

[Recommendation #1] *While shared mental models are important, new technologies should not burden workers with too much irrelevant information and should filter information and messages depending on one's duties, role, location, time, and cruciality of the information.*

If field teams receive too much information that is irrelevant to them and their duties, they could easily become distracted or overwhelmed, and start to miss or ignore important messages. Only the most important details, such as information relevant to the team's duties, basic bigger-picture details (such as *is everyone okay*, *has the subject been found*, etc.), and the teams' contributions to the bigger picture should be presented.

[Recommendation #2] *Before introducing more communication channels and information streams (such as videos, pictures, and text), designers should first focus on aggregating the existing channels together and presenting the information in a simplified way to the necessary people.*

While more information gives workers more ways of exploring the data they collect, it also increases the risk of mental overload. Thus, the information should be carefully managed, aggregated, and presented such as to not overwhelm the intended user. Based on our findings, we recommend presenting information in different ways (e.g., as a location on a map or an event on a timeline) and with different levels of detail, depending on who is viewing it and in what context they are viewing it. For example, if a manager pulls up a task assignment number, they may be interested in looking at the rough search path and the area covered. If a field worker pulls up the same assignment number, they may be interested in seeing lower-level details on the search techniques to carry out, the landmarks in the field to watch out for, and the equipment they need to bring with them. Moreover, a field worker may be interested in seeing the search path in relation to their own first-person view of the environment, whereas Command may be interested in seeing it overlaid on a map.

[Recommendation #3] *Given the mental and physical demands that workers face, WSAR communications should be as simple, minimal, quick, and distraction-free as possible.*

> This is true for both field workers and Command. For Command, technology should provide minimal distractions from planning and operations duties. For field workers, technology should provide minimal distractions from immediate surroundings, allow them to communicate hands-free if possible, reduce the time needed to send and receive messages, allow them to respond to less-crucial messages when they are less busy, and allow them to focus on listening and being on the lookout for the lost person.

Technology Designs

While WSAR agencies are starting to use more modern technology such as text and picture messaging, this can lead to multiple information streams, and the possibility of valuable information being overlooked. While the introduction of new technologies may come at a cost for SAR agencies, we believe that modernizing communication technology could ultimately bring benefits. In the following section, we introduce two design ideas for support WSAR distributed collaboration. The first aggregates multiple information streams into a single tabletop system. The second involves the use of drones as tools to allow managers at Command to communicate with and assist field teams on the ground; allowing Command to (a) see a field team in context with their surrounding environment and (b) communicate 'non-verbally' with the team via the drone's movements (e.g., movement cues for navigational instructions).

Terrain Table for Manager Awareness

Figure 3: The *WSAR Terrain Table*, a tangible interface for supporting SAR managers in building and maintaining higher-level awareness of an operation. From [22].

We designed a tangible interface for supporting managers at Command in building and maintaining awareness of an ongoing operation [22]. Called the *WSAR Terrain Table* (Figure 3), this interface brings together information from multiple sources and presents them in a single location, and thus is an early attempt at aggregating multiple information streams. The base of this tool is a physical terrain model of the search area. Placed over the terrain are physical props indicating information that remains constant or changes infrequently (e.g., the locations of the command posts). Projected over the terrain are digital representations of information that changes frequently, such as weather information (e.g., wind direction and speed, cloud cover), the makeup of the terrain (e.g., which parts are covered by snow, which parts are water and which are ground), the current locations of the field teams, the paths the teams have taken, and the locations of clues. This tabletop interface is intended to be placed in a convenient, accessible, and easy to see location in the command post. It is meant to support workers at Command in their management and planning duties by allowing them to inspect the statuses of the search environment, the field teams, and the progress of the search through visual observations from multiple viewpoints as well as via inspections through touch and physically handling objects on the terrain.

To illustrate a simple usage scenario: Elizabeth, a WSAR manager, is called to join an ongoing search response and take over for another manager, Lucy, who had been on duty for the past 12 hours. Elizabeth needs to familiarize herself with the progress of the operation and the status of the personnel and resources. Lucy briefs

Elizabeth with details about the operation, and while doing so, they both approach the tabletop and interact with it. Lucy also uses the interface to help demonstrate the key points she describes Elizabeth, communicating through both feedthrough (e.g., moving flags on the terrain) and deictic referencing (e.g., pointing to spots on the terrain where digital icons indicate that teams are located. She also gestures at areas where the interface shows there is cloud buildup, suggesting that a storm could be imminent. Lucy also presses her hands on some of the steeper mountains on the terrain, indicating to Elizabeth to instruct teams that she sends to those areas to bring the equipment necessary for steep ascents. Once Lucy is confident that Elizabeth is ready to take over, she hands her the manager vest and lets her take over.

Drones for WSAR Distributed Collaboration

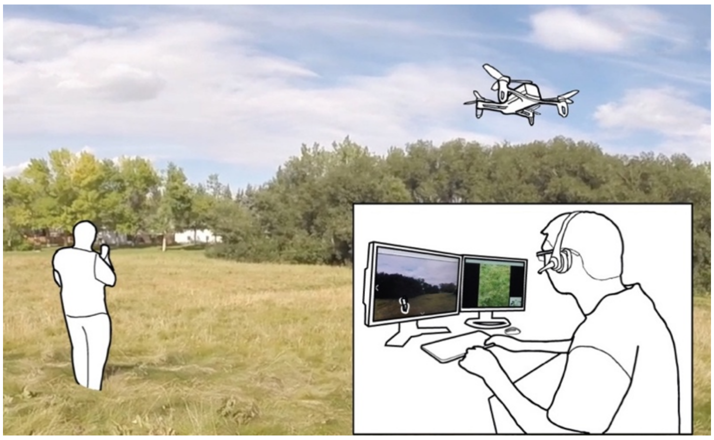

Figure 4: Drones can be used to enable video-based remote collaboration between a remote user indoors and a co-located user in the field. Such a setup could allow a worker at Command to assist a team in the field. Figure from [20].

We are also exploring the use of drones for supporting distributed collaboration in WSAR. Drones could provide a unique overhead perspective, which could be useful for both field workers and Command, allowing them to inspect the space from angles that would otherwise be unachievable [20]. This perspective could be especially beneficial for WSAR, as it allows workers to see things they would otherwise not be able to see from the ground; potentially even spotting the lost subject.

Drones can be used to accompany a field worker as they communicate with and receive assistance (e.g., navigational instructions) from a manager at Command. We have explored similar scenarios with general (non-WSAR) users in a previous study we ran [20]. In this work, we designed a drone-video-conferencing interface in which the drone follows the local (outdoor) user (Figure 4) and the remote (indoor) user views through the drone's camera feed (Figure 5). With this system, we ran a study with pairs of participants, one remote at an indoor location and the other outdoors with the drone. Pairs worked on activities involving searching through and organizing objects around a park. The local (outdoor) partner had to do the physical work required for the tasks, while the remote (indoor) partner had to assist using the visual information visible in the drone's camera view. We found that while this setup allows users to collaborate on such tasks more easily than with Skype-like video-chat interfaces, the introduction of the drone camera view brings about new challenges. For example, indoor users sometimes had difficulty translating navigational directions from the frame of reference of the drone to that of the local partner. For example, the indoor user might say *"move up"* or *"move down"*, though *up* and *down* from the perspective of the drone might translate to *forward* and *backward* from the perspective of the person on the ground. In addition, indoor users sometimes had trouble comprehending and contextualizing all of the information visible in the drone view. Outdoor users were sometimes distracted by the drone, but also saw it as a unique embodiment that could be used to convey non-verbal (consequential) communication from the indoor user. In this way, drones can be used as, for example, navigation tools (similar to [5,26,31,32]) controlled by Command to help guide a field team to an area that is difficult to find from the ground but easy to see from up in the air.

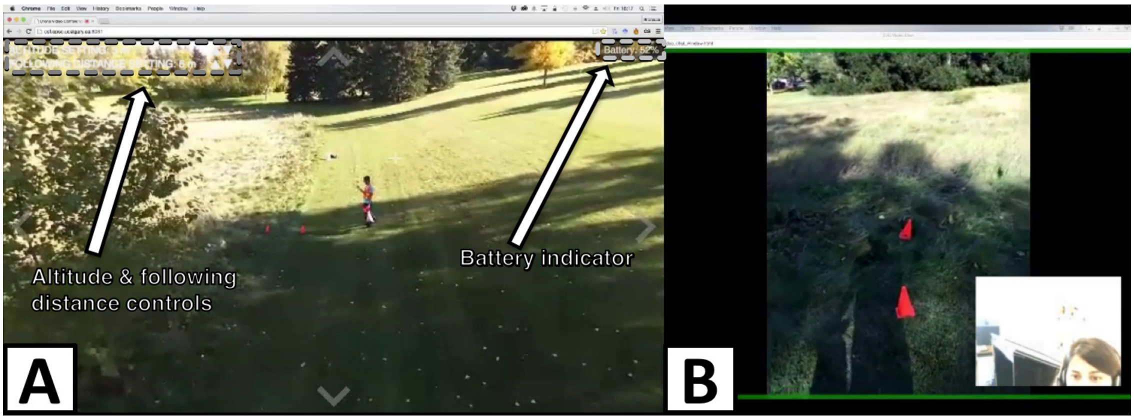

Figure 5: The interface for a video-conferencing system that allows an indoor user to assist an outdoor user with the help of a drone's camera view. Figure from [20].

Conclusion

Overall, our work opens up the design space for new technologies for supporting distributed collaboration in WSAR, with lessons that could also inform the design of technologies for distributed collaboration in other high-stakes activities taking place in network-sparse environments. Our investigative study outlined communication, awareness, and information-sharing activities and challenges of WSAR workers both in the field and at Command, as well as opportunities for design to address these challenges. We also presented design ideas to address these challenges. We plan to work closely with WSAR members and agencies to continue iterating on these designs and evaluate them to further understand the opportunities they bring and additional challenges that may need to be addressed.

Beyond WSAR, the findings from our work could potentially inform the design of remote-collaboration technologies for other high-stakes collaborative activities taking place in network-sparse situations. Such activities could include other types of SAR (e.g., urban, marine), military activities such as combat or peacekeeping, or large-scale disaster response in areas where communications infrastructure is down. Technologies that provide more opportunities for asynchronous communication could allow workers to share and receive information when they have a connection. When users do not have a connection, it would still be useful for technologies to attempt to provide valuable information and fill knowledge gaps. This could be done through displaying to the user (or reminding the user of) information that is already known and that is relevant in the current context or at the current location. E.g., a system that knows that the user is approaching a mountain could tell the user the current conditions of that mountain, such as snow buildup or the weather forecast. Such information would already be 'saved' or 'stored' on the device after having been fetched when in 'online' or in radio contact with others, but only provided to the user when it is needed. Another way this could be done is through providing statistical predictions of information that is not known, but can be inferred with what *is* known. E.g., the location of a colleague or team in a radio dead zone may not be known, but could be predicted using their last known location, their path or direction of travel (which may be known in an activity like WSAR if they have a task assignment), their speed of travel, and the amount of time that has passed. This prediction could be presented to a user who wants it, alongside a confidence rating. Lastly, technologies for remote collaboration in network-sparse conditions should warn users of 'radio dead zones', so that they are able to anticipate and plan for when they are about to enter such zones.

Acknowledgements

We thank the Natural Sciences and Engineering Research Council of Canada (NSERC), Alberta Innovates Technology Futures (AITF), and the University of Calgary for funding and supporting this research. We also thank the British Columbia (BC) Search and Rescue Association (BCSARA), SAR Alberta, and the SAR agencies and volunteers from BC and Alberta, Canada whom we have been in contact with for their ideas and their support of this work.

References

[1] Sultan A. Alharthi, Nicolas LaLone, Ahmed S. Khalaf, Ruth C. Torres, Lennart E. Nacke, Igor Dolgov, and Zachary O. Toups. 2018. Practical Insights into the Design of Future Disaster Response Training Simulations. In *Proceedings of the 15th International Conference on Information Systems for Crisis Response And Management*.

[2] Sultan A. Alharthi, Hitesh Nidhi Sharma, Sachin Sunka, Igor Dolgov, and Zachary O. Toups. 2018. Designing future disaster response team wearables from a grounding in practice. *Proceedings of Technology, Mind, and Society, TechMindSociety* 18, (2018).

[3] H. Artman and Y. Wærn. 1999. Distributed Cognition in an Emergency Coordination Center. *Cognition, Technology & Work* 1, 4 (December 1999), 237–246. DOI:https://doi.org/10.1007/s101110050020

[4] Nitesh Bharosa, JinKyu Lee, and Marijn Janssen. 2010. Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises. *Inf Syst Front* 12, 1 (March 2010), 49–65. DOI:https://doi.org/10.1007/s10796-009-9174-z

[5] Anke M. Brock, Julia Chatain, Michelle Park, Tommy Fang, Martin Hachet, James A. Landay, and Jessica R. Cauchard. 2018. FlyMap: Interacting with Maps Projected from a Drone. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays* (PerDis '18), 13:1–13:9. DOI:https://doi.org/10.1145/3205873.3205877

[6] Janis A. Cannon-Bowers, Eduardo Salas, and Sharolyn Converse. 1993. Shared mental models in expert team decision making. In *Individual and group decision making: Current issues*. Lawrence Erlbaum Associates, Inc, Hillsdale, NJ, US, 221–246.

[7] Michael D. Cardwell and Patrick T. Cooney. 2000. Nationwide application of the incident command system: Standardization is the key. *FBI L. Enforcement Bull.* 69, (2000), 10.

[8] Victor Cheung, Nader Cheaib, and Stacey D. Scott. 2011. Interactive Surface Technology for a Mobile Command Centre. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '11), 1771–1776. DOI:https://doi.org/10.1145/1979742.1979843

[9] Apoorve Chokshi, Teddy Seyed, Francisco Marinho Rodrigues, and Frank Maurer. 2014. ePlan Multi-Surface: A Multi-Surface Environment for Emergency Response Planning Exercises. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces* (ITS '14), 219–228. DOI:https://doi.org/10.1145/2669485.2669520

[10] Laura Dabbish, Robert Kraut, and Jordan Patton. 2012. Communication and Commitment in an Online Game Team. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12), 879–888. DOI:https://doi.org/10.1145/2207676.2208529

[11] Audrey Desjardins, Carman Neustaedter, Saul Greenberg, and Ron Wakkary. 2014. Collaboration Surrounding Beacon Use During Companion Avalanche Rescue. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing* (CSCW '14), 877–887. DOI:https://doi.org/10.1145/2531602.2531684

[12] A. Dix. 1994. Computer Supported Cooperative Work: A Framework. In *Design Issues in CSCW*, Duska Rosenberg and Christopher Hutchison (eds.). Springer, London, 9–26. DOI:https://doi.org/10.1007/978-1-4471-2029-2_2

[13] Mica R. Endsley. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Hum Factors* 37, 1 (March 1995), 32–64. DOI:https://doi.org/10.1518/001872095779049543

[14] Elliot E. Entin and Daniel Serfaty. 1999. Adaptive Team Coordination. *Hum Factors* 41, 2 (June 1999), 312–325. DOI:https://doi.org/10.1518/001872099779591196

[15] Stephen M. Fiore and Eduardo Salas. 2004. Why we need team cognition. In *Team cognition: Understanding the factors that drive process and performance*. American Psychological Association, Washington, DC, US, 235–248. DOI:https://doi.org/10.1037/10690-011

[16] Elena Gabor. 2015. Words matter: radio misunderstandings in wildland firefighting. *Int. J. Wildland Fire* 24, 4 (June 2015), 580–588. DOI:https://doi.org/10.1071/WF13120

[17] Stephen E. Hannestad. 2005. Incident command system: A developing national standard of incident management in the US. In *Proc of ISCRAM Conference*.

[18] Christian Heath and Paul Luff. 1992. Collaboration and control: Crisis management and multimedia technology in London Underground Line Control Rooms. *Comput Supported Coop Work* 1, 1–2 (March 1992), 69–94. DOI:https://doi.org/10.1007/BF00752451

[19] James Hollan, Edwin Hutchins, and David Kirsh. 2000. Distributed Cognition: Toward a New Foundation for Human-computer Interaction Research. *ACM Trans. Comput.-Hum. Interact.* 7, 2 (June 2000), 174–196. DOI:https://doi.org/10.1145/353485.353487

[20] Brennan Jones, Kody Dillman, Richard Tang, Anthony Tang, Ehud Sharlin, Lora Oehlberg, Carman Neustaedter, and Scott Bateman. 2016. Elevating Communication, Collaboration, and Shared Experiences in Mobile Video Through Drones. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (DIS '16), 1123–1135. DOI:https://doi.org/10.1145/2901790.2901847

[21] Brennan Jones, Anthony Tang, and Carman Neustaedter. 2020. Remote Communication in Wilderness Search and Rescue: Implications for the Design of Emergency Distributed-Collaboration Tools for Network-Sparse Environments. *Proceedings of the ACM on Human-Computer Interaction* 4, GROUP (2020). DOI:https://doi.org/10.1145/3375190

[22] Brennan Jones, Anthony Tang, Carman Neustaedter, Alissa N. Antle, and Elgin-Skye McLaren. 2018. Designing a Tangible Interface for Manager Awareness in Wilderness Search and Rescue. 161–164. DOI:https://doi.org/10.1145/3272973.3274045

[23] Justice Institute of British Columbia. 1999. *Ground Search and Rescue (GSAR) Manual* (2nd ed.). Justice Institute of British Columbia. Retrieved from http://www.jibc.ca/sites/default/files/emd/pdf/SAR100%20GSAR%20Participant%20Manual.pdf

[24] Justice Institute of British Columbia. 2015. Search and Rescue Management Level 1 Participant Manual (Selected Pre-Read Material). Retrieved from http://www.jibc.ca/sites/default/files/emd/pdf/EMRG_1783_PreRead_Chapters_for_Web_20150624.pdf

[25] Nafiz Khan. 2019. An Exploratory Study of the Use of Drones for Assisting Firefighters During Emergency Situations. In *CHI 2019: Proceedings of the 2019 SIGCHI Conference on Human Factors in Computing Systems*. DOI:https://doi.org/10.1145/3290605.3300502

[26] Pascal Knierim, Steffen Maurer, Katrin Wolf, and Markus Funk. 2018. Quadcopter-Projected In-Situ Navigation Cues for Improved Location Awareness. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18), 433:1–433:6. DOI:https://doi.org/10.1145/3173574.3174007

[27] Wendy E. MacKay. 1999. Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control. *ACM Trans. Comput.-Hum. Interact.* 6, 4 (December 1999), 311–340. DOI:https://doi.org/10.1145/331490.331491

[28] Emily S. Patterson, Jennifer Watts-Perotti*, and David D. Woods. 1999. Voice Loops as Coordination Aids in Space Shuttle Mission Control. *Computer Supported Cooperative Work (CSCW)* 8, 4 (December 1999), 353–371. DOI:https://doi.org/10.1023/A:1008722214282

[29] Kate Starbird. 2013. Delivering Patients to Sacré Coeur: Collective Intelligence in Digital Volunteer Communities. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13), 801–810. DOI:https://doi.org/10.1145/2470654.2470769

[30] Kate Starbird and Leysia Palen. 2013. Working and Sustaining the Virtual "Disaster Desk." In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work* (CSCW '13), 491–502. DOI:https://doi.org/10.1145/2441776.2441832

[31] Daniel Szafir, Bilge Mutlu, and Terrence Fong. 2014. Communication of Intent in Assistive Free Flyers. In *Proceedings of the 2014 ACM/IEEE International Conference on Human-robot Interaction* (HRI '14), 358–365. DOI:https://doi.org/10.1145/2559636.2559672

[32] Daniel Szafir, Bilge Mutlu, and Terry Fong. 2015. Communicating Directionality in Flying Robots. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction* (HRI '15), 19–26. DOI:https://doi.org/10.1145/2696454.2696475

[33] Zachary O. Toups and Andruid Kerne. 2007. Implicit Coordination in Firefighting Practice: Design Implications for Teaching Fire Emergency Responders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '07), 707–716. DOI:https://doi.org/10.1145/1240624.1240734

[34] Zachary O. Toups, Andruid Kerne, William Hamilton, and Alan Blevins. 2009. Emergent Team Coordination: From Fire Emergency Response Practice to a Non-mimetic Simulation Game. In *Proceedings of the ACM 2009 International Conference on Supporting Group Work* (GROUP '09), 341–350. DOI:https://doi.org/10.1145/1531674.1531725

[35] Murray Turoff, Michael Chumer, Bartel Van de Walle, and Xiang Yao. 2004. The design of a dynamic emergency response management information system (DERMIS). *Journal of Information Technology Theory and Application (JITTA)* 5, 4 (2004), 3.

[36] Himanshu Zade, Kushal Shah, Vaibhavi Rangarajan, Priyanka Kshirsagar, Muhammad Imran, and Kate Starbird. 2018. From Situational Awareness to Actionability: Towards Improving the Utility of Social Media Data for Crisis Response. *Proc. ACM Hum.-Comput. Interact.* 2, CSCW (November 2018), 195:1–195:18. DOI:https://doi.org/10.1145/3274464

[37] FHWA Office of Operations - Glossary: Simplified Guide to the Incident Command System for Transportation Professionals. Retrieved April 2, 2019 from https://ops.fhwa.dot.gov/publications/ics_guide/glossary.htm

[38] goTenna Pro - Lightweight, Low-cost Tactical Mesh-Networking Comms. *goTenna Pro*. Retrieved June 20, 2019 from https://gotennapro.com/