Remote Communication in Wilderness Search and Rescue: Implications for the Design of Emergency Distributed-Collaboration Tools for Network-Sparse Environments

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Wilderness search and rescue (WSAR) requires careful communication between workers in different locations. To understand the contexts from which WSAR workers communicate and the challenges they face, we interviewed WSAR workers and observed a mock-WSAR scenario. Our findings illustrate that WSAR workers face challenges in maintaining a shared mental model. This is primarily done through distributed communication using two-way radios and cell phones for text and photo messaging; yet both implicit and explicit communication suffer. WSAR workers send messages for various reasons and share different types of information with varying levels of urgency. This warrants the use of multiple communication modalities and information streams. However, bringing in more modalities introduces the risk of information overload, and thus WSAR workers today still primarily communicate remotely via the radio. Our work demonstrates opportunities for technology to provide implicit communication and awareness remotely, and to help teams maintain a shared mental model even when synchronous realtime communication is sparse. Furthermore, technology should be designed to bring together multiple streams of information and communication while making sure that they are presented in ways that aid WSAR workers rather than overwhelming them.

CCS Concepts: • **Human-centred computing** → Collaborative and social computing; *Empirical studies in collaborative and social computing*

KEYWORDS

Search and rescue, outdoors, team communication, distributed collaboration, awareness

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1 INTRODUCTION

Wilderness search and rescue (WSAR) involves the search for and extraction of one or more lost people (e.g., hikers, skiers) from a wilderness area. WSAR is a time-critical operation that

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requires careful communication and collaboration between many workers who are spread out in various locations, including at a command post (Fig. 1, left) and in the field (Fig. 1, right). However, operations usually take place in areas with poor cellular coverage where geographic features such as mountains and valleys can block radio signals, making consistent realtime communications between all team members difficult. Team members do not always have direct communication links with each other, and sometimes field teams spend long periods of time being unable to contact anyone else in the operation at all. In this work, we study how this affects remote collaboration in WSAR.

Researchers have explored technologies for planning and collaboration in search and rescue (SAR) [1,56], as well as other emergency domains such as firefighting [46,64], avalanche rescue [21,22], and crisis response [2,4,16,17,62,65]. In all of these domains, workers need to build and maintain a nuanced shared mental model [10] of the progress made in the operation and the status of teams, workers, and equipment; and project that knowledge to understand what will happen next and make future plans. This shared mental model is created and maintained through shared situational awareness (SSA) [25], team awareness [12], and distributed cognition [57]. In our work, we focus on *remote collaboration* in large-scale WSAR operations, mainly on the *search* phase, where multiple teams are deployed in the wilderness to cover a large search area looking for a lost person. Despite the related literature, we do not know what challenges WSAR workers face as a result of the wilderness and a lack of realtime communication. We explore this through a CSCW and technology-design perspective in order to inform the design of technologies to support distributed collaboration between responders in high-stakes emergency situations in which realtime communication and awareness are not always possible. In our work, we focus on a Western-Canadian perspective of WSAR, which is an environment containing many forests, mountains, rivers, and lakes.

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

To tackle our research goals, we interviewed 13 WSAR volunteers, including four managers and five field team leaders, and observed a full day WSAR mock-search training activity. Our findings indicate that WSAR workers communicate remotely for various reasons and share varied information with different levels of urgency, warranting the use of multiple communication modalities (e.g., voice, text, photos, videos, GPS locations, etc.). However, communications between the field and command today still largely happen via a single information stream: the radio. This reduces the opportunities for implicit communication and awareness between field workers and command, which can lead to difficulties maintaining team awareness and cognition [12,27,38], especially in large searches that take place over a long period of time.

These findings demonstrate that WSAR workers, teams, and agencies could benefit from multiple channels of communication and awareness, both synchronous and asynchronous, and each tailored to their specific purposes and needs. Making information available in multiple formats (e.g., audio, pictures, videos) from multiple channels could help better support building a shared mental model, as it could allow for different ways to interpret and understand what is happening. However, these streams of information should be presented in ways that aid WSAR workers rather than overwhelming them, presenting information that is *actionable*. Furthermore, given that the work of Command is heavily reliant on information coming in from field teams, design should focus more on communication and awareness between the field and Command. This work makes the following contributions: (1) a study revealing insights about wilderness SAR communication contexts and goals, common communication challenges, and design needs for each context; and (2) discussion of potential design solutions and recommendations for future work.

2 WILDERNESS SEARCH AND RESCUE

In a typical Canadian WSAR scenario, an agency from a nearby community is called to respond to a report of a missing person [42,43] (often called the *subject* of the search). The *SAR manager* on duty for the agency sends a callout to volunteer members of the agency to meet at a specific location near the search area. When the members arrive, they form one or more *field teams* that search assigned parts of the search area. The manager and their management team work from a *command* post (a mobile-office trailer parked near the search area) in advance of the members' arrivals. Here, they plan specific search assignments (e.g., which areas to search, which search techniques to use, etc.) and give assignments based on the members available and their skills and backgrounds. Search plans are drawn up based on the information the agency has on hand about the subject, such as their last know location, their direction of travel, and other knowledge about their behaviour. Probability maps are created based on this information using statistics and years-worth of data describing how lost people typically behave in the wilderness [48]. The Command team is responsible for coordinating a large number of people, keeping track of vast amounts of information, and using that information to construct future plans of action.

For more serious incidents (e.g., where multiple people are lost), multiple agencies and their members are called to mutually assist the agency receiving the initial callout. When this happens, each agency has its own secondary manager and management team, while the manager from the team receiving the initial callout remains the primary higher-level manager. Each agency then sends out its own field teams based on the advice of the primary management team.

Field teams traverse assigned locations, searching for the lost subject(s) through careful listening and observation. Search techniques can range from a precise search, in which a smaller area is covered in a lot of depth, to a broader search, in which a larger area is covered in a short amount of time but with less precision. Workers are specially trained in navigating tough environments such as rapid river crossings, steep mountain climbs, and deep snow. Field teams report to Command, via two-way radio communications, any information that may be important in figuring out where the subject is (e.g., footprints, objects left behind). Lastly, if a team finds the subject, they report this back to Command via the radio and begin the process of safely extracting them and moving them to safety.

We mainly focus on the *search* aspect of WSAR. As soon as the subject is found, the dynamic changes from mainly information collection and planning (akin to puzzle solving), to recovery and ensuring the safety of the subject(s). Additionally, during a large search, teams are scattered in different locations and Command needs to keep track of all of them; whereas in a rescue-only operation, if the location of the subject is already known, Command typically only has to send one team out to extract them. During such operations, this single team has far greater ability to communicate with one another via easier means; e.g., yelling at one another, using radios that do not face reception issues due to workers being closer together, etc. On the other hand, a large search operation that *turns into* a rescue operation is different, in that Command still needs to deal with all of the other teams once the subject has been found. They either have to give them roles to play in the treatment and extraction of the subject, recall them back to base, or tell them to be on standby. If there are multiple subjects to extract in different locations, then it is similarly complicated. While we are interested in a variety of WSAR operations, both search and rescue, we put the bulk of our focus on operations that start as large searches, as they are complicated responses involving multiple personnel and a lot of resources, in an activity that is akin to distributed collaborative problem solving. We do this with the idea that our findings and insights could also be applied to simpler responses involving fewer people and less resources.

3 RELATED WORK

3.1 Team Cognition and Awareness

WSAR, especially large operations, requires a lot of structured team work, collaboration, and coordination across distances. Early research has promoted the idea that a *shared mental model* [10], or shared understanding and awareness of the activity and the things that comprise it, helps maintain strong team cognition [5,10,51,53]. A shared mental model is important for large collaborative activities involving many people and resources, including WSAR responses. Thus, work procedures, the technology in use, and WSAR workers' behaviours around such technologies should be in service of supporting a shared mental model. To support a shared mental model, it is also essential to support *team cognition* [27,38] across distances. Team cognition has been studied extensively in CSCW research [3,5,10,12,24,27,33,38,53], and is the shared knowledge and awareness of team members, work processes, tasks, and the workspace; and the ability to coordinate and act together based on that shared knowledge. It is often supported by *distributed cognition* [38,39,58], which is the idea that knowledge is distributed in the workspace and the artifacts contained within it. Awareness, which is important for team cognition [33], is difficult to establish and maintain over distance [12,25,26,34]. In WSAR, members generally go through the same training and use the same language and communication protocols while working together and passing along information [42,43], although these standards could vary slightly across jurisdictions. The *Incident Command System* (ICS) [11,35,69], now part of the US National Incident Management System (NIMS) [66,69], is a standard emergency protocol developed and used extensively in emergency management over the last few decades around the world, and it is the central underpinning of how roles and tasks are assigned and how information flows in WSAR in Canada [42,43]. ICS is a core part of the shared mental model of WSAR and other emergency domains, given that it helps emergency responders communicate and collaborate using shared language and protocols they agree on [6]. WSAR standards and protocols allow multiple agencies to use the same shared language when, for example, one needs to provide mutual aid to another person [42,43]. In addition, ICS allows emergency responders from multiple domains (e.g., EMS, firefighters, police, etc.) to collaborate using a common language [66,69].

More recent research in CSCW has argued that shared mental models are not always necessary for successful collaboration during team activities, as collaborators do not necessarily need to have the exact same knowledge to complete a task together [12]. For example, if work is decoupled [59] and each team member is playing a distinct role or taking on a unique task (but each task and role builds up to form the larger activity), then each team member will have unique knowledge and a unique perspective. In this case, sharing knowledge may not always be beneficial, and in some cases if it is irrelevant knowledge, it may be distracting to the task at hand [12]. Rather, just having a shared sense of the team's goals and objectives and awareness and understanding of who on the team knows what and what everyone's capabilities are may be sufficient enough. As a result, it is also useful to understand other theories that can contribute to an understanding of how team collaboration can be successful. These include *team awareness* [12], *situation awareness* [25], and *workspace awareness* [32,34]. Team awareness is one's awareness and understanding of the presence, activities, and characteristics of their team members, as well as the larger makeup of the team [12]. It involves an understanding grounded in the team's culture, reaching common ground [18], and understanding one's role as an individual within the team [12]. Situation awareness is the ability to perceive and understand one's own current situation and use that understanding to make proper decisions and project one's future status [25]. Workspace awareness is an understanding of who is 'in' the workspace and what is happening and has happened within its temporal and physical bounds [34]. It is an understanding of who is and has been present in the 'workspace' (or activity at hand), what they are doing within it, what their contributions have been, and how the state of the workspace, including the artifacts and information within it, have changed [34].

Collaborative coupling is the degree to which team members' work is reliant on one another [59]. Collaborative work is *tightly coupled* if team members rely on other team members to complete their work and *loosely coupled* if they do not [53,59]. Rather than work being explicitly tightly or loosely coupled, most collaborative work actually falls within a spectrum roughly somewhere between tightly and loosely coupled [34]. In some cases, collaborators switch back and forth between individual and collaborative work [24,29]. While doing so, it often helps for workers to be aware of their team members' activities, as it helps them understand when they are available for collaboration and assistance [36].

In our work, we aim to understand how WSAR workers and teams, through their domain-specific training, try to build and maintain *team cognition*, *awareness*, and a *shared mental model* in large search operations. We focus on this throughout our findings. We also focus on where their work practices, as well as the technologies they use, are failing them. Beyond just WSAR, some of our findings could also apply to the circumstances to the basic situation that WSAR introduces; i.e., intermittent and unreliable connectivity, not only between the field and Command, but also between the different field teams. These findings could contribute nuance into how we should think about supporting shared mental models, awareness, and team cognition in network-sparse conditions.

3.2 Search and Rescue

SAR in various contexts (e.g., urban, wilderness) has been extensively studied by researchers in HCI, Human-Robot Interaction (HRI) [31,54], and CSCW [1,21,22,56]. HRI researchers have studied the use of robots such as drones [19,23,30,41,52,70] and land rovers [8,13,47,60] for SAR, and found that control interfaces for such robots should be designed to provide as much spatial and situation awareness of the surrounding environment as possible. Robots have been used in real SAR incidents since at least the 9/11 attacks [13]. Many robots have capabilities that go beyond those of humans and are able to search through areas or from perspectives that humans cannot ever reach by themselves. The obvious example is drones [19,23,30,41,52,70], which can inspect large swaths of wilderness environments from overhead perspectives in a relatively inexpensive way (compared to helicopters and airplanes) [19,30].

Cooper and Goodrich [19] explored the design of interfaces for WSAR field workers to control and view information from a drone. Through their explorations, the authors found that control and information presentation should be simplified, as too much information and control could increase the time and overhead in completing a task. The high-stress nature of the operation can further exacerbate this. Desjardins et al. [22] found the same thing in their explorations of co-located collaboration around beacons during avalanche rescues. Both of these works also found value in presenting information in relation to the layout and physical makeup of the outdoor space. Furthermore, Alharthi et al. [1] found that a sizeable amount of planning and discussion of plans is centred around maps. They recommend mixing individual and team maps, mixing digital and physical maps, and providing the ability to modify and populate maps. We are interested in seeing if such design practices could be extended to remote collaboration activities, such as information sharing between ground search teams and Command.

WSAR planning involves building probability maps based on the characteristics of the lost person using statistics grounded in years-worth of data describing how lost people typically behave in the wilderness [48]. Planning maps indicate the last known position of the subject as well as coloured zones indicating the probability that the subject would be found in that particular area [42,43,48,49]. From these probability maps, SAR managers draw out search paths and define the search techniques that the field teams would carry out [43]. In many cases, the search area grows larger by the minute [42,43,48,49], so WSAR workers must respond quickly and efficiently to increase their chances of finding the subject alive. Search plans are often constructed through proven lost-person behaviour models such as those from Koester [48] and Koopman [49]. There also exist computer programs and mobile apps (e.g., [71]) that help SAR teams build and follow search plans based on proven WSAR models.

This literature tells us a bit about the nature of WSAR. It tells us that managers and planners need to keep track of what has and has not been searched, where everyone is located, how resources are being allocated, and various other things; and use that to plan future actions based on proven WSAR probability models. They need strong team cognition, awareness, and a shared mental model for this. We want to understand how they get the information that they need for these actions while distributed in network-sparse environments. Furthermore, we are interested in understanding the nuances of how WSAR remote collaboration around the information collected and the use of probability models takes place, and how it can be better supported with newer technologies.

3.3 Emergency Response and Control Rooms

In other team situations such as firefighting [46,64], there are a number of workers 'on the ground' responding to an emergency, communicating carefully with each other, and answering to an *Incident Commander* (the main person in charge of the incident response [69]) at a base (e.g., a command post or a fire engine) [42,64]. There is both explicit [28] and implicit [64] communication taking place, and workers have to be highly trained in communicating [28,42], coordinating [42,64], and using the radio [28,42]. Toups and Kerne [64] found that firefighters use implicit coordination, i.e., communicating in-person via words and non-verbal gestures, and seeing each other's actions and intentions, to plan and guide their actions as a team. In large WSAR operations, workers and teams are distributed across large distances, thus reducing opportunities for face-to-face interactions that one might see in firefighting. We explore how WSAR workers try to perform similar coordination actions as firefighters yet over distances today, what role these actions play in the overall operation, and what opportunities exist for technology to provide this support in WSAR. To dates, studies have not uncovered this knowledge.

One major challenge in emergency situations is "how do you get the right *information* to the right *people* at the right *time*?" *Actionability* refers to the idea that certain information is relevant, or *actionable*, to a certain person depending on the role they play, the context they are in, and the time [67]. Information that is useful to some people in certain contexts and times may be useless to others, at different times, and/or in different contexts [67]. In WSAR, Command has a lot of information, mostly coming from field teams, but occasionally from external sources such as police, the victim's family, and/or weather agencies [42,43]. This information is aggregated, processed, and made sense of over time. Command workers use the raw information to then process new information such as task assignments, paths to traverse, and probability charts (i.e., the probability that the lost subject will be found in a certain area) [42,43,48]. This information then needs to be passed on to the relevant workers in the field at the right time. Relevance in this case could depend on, for example, one's role, task assignment, skills, search strategy, and location in the field. To date, research has not explored how WSAR command workers determine which information is actionable to which people, how command workers pass on this information to the right people, and how this whole process can be improved and/or expedited; this is our focus.

The collective actions of WSAR workers may be similar to the collaborative control-room environments that have been studied in previous work—for example, metro-system control rooms [37], space-shuttle mission-control centres [55], and air-traffic control rooms [50]. Implicit and consequential communication are common in these types of settings. These studies have shown that being able to constantly observe [37], hear [55], and read the intentions of [37] colleagues helps in proper planning and decision making for complex group activities requiring high amounts of focus, collaboration, and coordination. While there is collective action in WSAR, workers in large part do not operate as a single collective. Rather, because they are spread out and more often than not disconnected from each other, teams are operating semi-autonomously and do not necessarily know what every team has seen, nor how that relates to their situation. Our focus is on how this affects WSAR distributed collaboration, and how we can tackle this through technology design.

4 STUDY METHOD

The research gap we aim to fill is an understanding of the challenges that WSAR personnel face in trying to build and maintain a shared mental model while moving between varying states of radio connectivity. This could also contribute to a higher-level goal of attaining a better understanding of the nature of collaborative work in network-sparse environments; as much of what has been explored in CSCW research to date has instead touched on co-located work (e.g., [37,50,55]) or distributed work where connectivity is at least mostly reliable (e.g., [64]).

To work toward this understanding, we conducted a study of WSAR volunteers, looking mainly at work practices, the challenges that workers face as a result of the wilderness and a lack of realtime communication, and their workarounds to such challenges. This study was approved by our research ethics board. This study was conducted in two components: (1) an *interview* component, and (2) an *observation* component.

4.1 Interviews

First, we conducted extensive one-on-one interviews with WSAR workers. The purpose was to have participants reflect more broadly on their experiences with WSAR across multiple incidents.

Participants. We interviewed 13 WSAR volunteers (11 men, two women), including four SAR managers and five field team leaders, in order to better understand the challenges from both the field and command-post perspectives. We recruited interview participants from volunteer WSAR agencies in Western Canada through social media, word of mouth, and by contacting individual agencies. The agencies that our participants volunteered for served various communities, small and large, around Western Canada, all near wilderness regions containing mountains, lakes, rivers, and forests. Our interview 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.

Method. The interviews were approximately one-hour long, semi-structured, and took place over the phone, via video calling, or in-person (depending on the availability and location of the participant). We asked participants about their communication practices, their needs, how they use current technology to communicate during WSAR operations, the challenges they face, and how they overcome such challenges. We mainly centred our questions around stories of real scenarios by asking participants to recount past incidents and focus their telling of the incidents on the communication, collaboration, and information-sharing practices and challenges. Sample questions and prompts that we gave participants included *"tell a story about a situation you've experienced in which communication to Command broke down"* and *"tell a story about a situation you've experienced in which it was difficult to make sense of incoming information from field teams."*

4.2 Observation

To complement our interviews and to see first-hand some of the experiences that WSAR workers told us about, we observed a simulated WSAR exercise where volunteers from various nearby WSAR agencies searched for fictional lost subjects in a forested and mountainous wilderness area near a medium-sized city in Western Canada. This day-long (eight hour) mock WSAR operation was organized and hosted by a local SAR agency to train volunteers. The event simulated the entire experience of a normal WSAR operation, including a missing person phone call, callouts to the volunteers, setting up a mobile office trailer on site, organizing and sending out search teams, and so on. Only top-level organizers, who were not involved in the simulation as participants, knew all of the details of the simulation, so managers operated without necessarily even understanding where the bounds of the search area were.

Over 100 WSAR volunteers from 14 local SAR agencies nearby searched for 15 fictional lost subjects (who themselves were volunteers from a nearby community) in this exercise. The lead researcher on our team observed the mock search in its entirety from the operations vehicle at the command post (with permission). The researcher acted as a fly-on-the-wall in the operations vehicle, observing and taking notes on the communications coming in from the field teams via the radio, the reactions of the people in the command vehicle to the incoming radio communications, the outgoing communications from Command to the field teams, and the co-located communications happening within the command vehicle (e.g., field teams handing in debrief forms as they return to base, members of the management team sharing information, etc.). Whenever volunteers were not busy, we asked about the things they did, why they did them, what worked well in their duties, and what challenges they face related to information sharing. We were unable to get a researcher to observe from the field perspective due to safety and liability concerns.

4.3 Data Collection and Analysis

The interviews were audio recorded and transcribed. For the observation component, a researcher took thorough notes of what happened in the command vehicle. We used open, axial, and selective coding to analyze both the interview and observation data and reveal higher-level themes. Open codes included things like *location awareness*, *sending information*, and *recording information*, while axial codes included categorizations of the open codes such as *awareness* and *information sharing*. Our selective codes and themes included *communication goals*, *communication challenges*, and *workarounds to communication challenges*. The lead researcher on our team did most of the coding, but the codes and what they pointed at (e.g., what they described shorthand) were reviewed collectively and iteratively by the other two researchers on our team throughout the data-collection and coding phases. We looked at these goals and challenges from the perspectives of both field and Command workers, to understand the similarities, differences, and tensions between their needs and circumstances.

We now discuss our findings. Interview-participant quotes are listed with *'P#'* indicating which participant gave the quote followed by the main role that she/he indicated taking on (*Field Worker*, *Field Team Leader*, or *SAR Manager*). For quotes from the mock-search activity, we indicate the role played by the person being quoted.

5 FINDINGS

5.1 Documentation, Logging, and Awareness

At Command. We found that SAR managers rely heavily on written forms, physical artifacts, and their positions in the command office (Fig. 2) in maintaining an operational picture and shared mental model. This information is useful for planning, record keeping, and maintaining situation awareness of the statuses of teams and resources, especially when unable to directly observe them. Through these forms, command workers can still be aware of what everyone is supposed to be doing and make predictions (based on how much time has passed) of how much progress each team has made in their assignments. In direct accordance with distributed cognition, knowledge is contained in the artifacts spread out across the command vehicle.

When the first SAR managers arrive at the scene and after they have set up the staging area with the command vehicle(s), they begin filling out forms. We observed that these forms include (but are not limited to): a subject description, ICS forms indicating the roles and tasks to be assigned, and maps of the search area including probabilities and search paths. As volunteers arrive at the staging area, they report to the manager on duty and sign in. Once the management team finishes creating a response plan, they call all the volunteers on site and do an initial briefing.

Fig. 2. The inside of the command vehicle, where the SAR manager and her management team oversee the operation and coordinate field teams. The command post is filled with written forms and physical artifacts placed over walls, desks, and whiteboards.

During the simulated response we observed, the management team first gave the volunteers a task number, followed by describing the scenario. In this training scenario, it was a helicopter crash in the forest, and there were 15 crew members on board who were now missing. They gave the time of the crash, descriptions of the subjects and the aircraft, the estimated location of the crash based on eyewitness reports of where the helicopter was flying before it crashed, and the types of clues that the volunteers should be on the lookout for. Volunteers were given a short description of the search area, including what features (hills, streams, boulders, etc.) were contained within it. They were also told safety information such as the weather forecast, the recommended clothing, and amount of water needed. While all of this information was being told, we observed volunteers taking notes in pocket notebooks which they then carried with them into the field.

Volunteers were then organized into teams, and each team was assigned one experienced SAR worker to be the team leader. The teams were then given their task assignments. For each team, a manager briefed the team leader, who would then brief the rest of the team. Command gave each team a set of paper maps and forms with the subject description, and notes on the type of search to conduct, which locations to search, and what to be on the lookout for. Field teams were to rely on this information when out in the field performing their duties. Both Command and the field team had a copy of the same task and role assignment forms. Photocopies were made immediately after the forms were filled, so that Command could keep a copy to place on the wall. This allowed them to keep track of who was deployed in the field and what they were doing. Each team carried at least one GPS-equipped radio transceiver with them for communicating with Command. When teams returned, they would do a post-assignment debrief, their forms would be returned to management, and management's copies of the forms would be moved to a section of the wall showing the completed assignments.

> *"We use whiteboards and erasable pens. We also use the physical team assignments, so we'll write the team assignment, what they're doing, where they're going, and then once they check in that they're in the field, then we move [the form] to a different location [on the wall], so now we know they're in the field." – P4 (SAR Manager)*

> *"The team leader will take a photocopy of that task sheet with him/her out into the field and the original will stay at Command. When the team comes back in, the team leader will [...] do a written record of what they did, what they encountered, what they found, all that stuff. And then [the] team leader will sit down with someone from Command and go over it." – P6 (Field Worker)*

We observed that the management team carefully logged all radio communications. During the search phase, all radio communications between the field teams and Command took place on a single radio frequency. The SAR manager assigned one person to be the *communications officer*. This person was in charge of talking to teams in the field on the radio on behalf of Command, and logging all of the radio communications that take place. We observed that this logging is precise, complete, and extensive, with the goal for there to be as much accuracy as possible. The communications officer did not necessarily log each message word-by-word, but rather logged each higher-level 'communication event' in a row on a spreadsheet with the following four columns: (1) who the message was from; (2) who the message was to; (3) the time of the message; and (4) a higher-level summary of the message, event, or reason for the communication. There were two reasons Command was logging this information: (1) to keep a time log of key events to possibly refer to later, and (2) to protect themselves for liability purposes.

> *"If we're walking along the road and I find a gold bracelet with a cross on it on the side of the road, I'll radio Command [...] They'll log that. [...] Then let's say the next day the family members come up and say 'oh we forget to tell you that little Susie has a gold bracelet with a cross on it.' We can go back and look at that record and say 'oh we found this bracelet at this location at this time.'" – P11 (Field Worker)*

This allows the knowledge to be stored in an artifact after transmission from the field to Command, and used at a later time, possibly by other workers. In accordance to distributed cognition, this piece of knowledge is thus contained in the workspace and belongs to the responding organization, rather than just a few individuals within it.

In the Field. Field teams also relied on documentation (consisting of both forms they and management filled out, as well as hand-written notes) to recall what they were supposed to do and where they were supposed to go. However, 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.

> *"[Field teams] know who they're looking for and the generals, but they don't need to know what the big picture of the search is. They're going to go to the area that they're told to, [but] they may not even know why." – P4 (SAR Manager)*

The best case meant that conditions in the field were as Command expected them to be, and the field team did not run into any unusual or unanticipated challenges. However, this was not always the case. Sometimes a field team would run into an obstacle that prevented them from conducting their search assignment exactly as they were requested to. For example, in the simulated search we observed, a team radioed Command to inform them that they were observing more trails around them than were shown on the map that they were given. Later in the operation during the rescue stage, another team that was searching for more subjects on their way to the crash site encountered boulders along the route they were supposed to take, and they could not pass through. Thus, they had to take an alternate route. They informed Command on the radio and also shared the location of the boulders, so that Command could keep track and perhaps inform other teams in the area.

5.2 Consistency, Agreement, and Control

Our analysis showed that WSAR workers used documentation and communications to maintain a shared mental model on key aspects of the operation (e.g., shared agreement and common ground on what was to be done). Command did not want there to be discrepancies in what a team is doing and what Command expects them to be doing. They wanted consistency, clarity, control, agreement, and shared understanding. When a team did something that was unexpected, Command needed to know why. A single team deviating can affect the entire operation, and Command may need to adjust their operation plan around changing conditions in the field or a team deviating.

> *"As a non-military organization, we sometimes face the issue of giving a field team leader a task, only to realize they decided to do something they thought was more 'important'." – P13 (SAR Manager)*

There are sometimes valid reasons for field teams to occasionally deviate from their assignments, and Command often knows this. During an operation, Command does not experience the conditions of the field first-hand, so they are not always able to judge for themselves whether or not a course of action can be taken. They generally trust the team leader to make that call:

> *"[We're] content to just let them do their job. [...] We don't need to micromanage. We can trust the team leader to make sure that things are being done correctly. But having said that, we still need constant radio communications or equivalent because of changing information." – P10 (SAR Manager)*

> *"All kinds of things can happen. Maybe [there are] some natural features there, it all looks great and flat and clear on a map in the command post where I'm warm and dry, but out in the field, the reality [could be different]." – P4 (SAR Manager)*

Nevertheless, Command still needed field teams to inform them of when they deviate, and for what reason. When they did this though, this communication was not always clear, especially over the radio:

> *"The helicopter pilot dropped me in the wrong place [...] and I let command know, [but] they didn't quite understand. When I got back with my team, it's like 'Where did you go?' 'Well, here.' 'Why did you go there?' I'm like 'Because the helicopter couldn't land there, so we searched the area we were in.'" – P4 (SAR Manager; describing an incident when he played the role of Field Team Leader)*

In order to make sure that teams are on track, Command generally wants to maintain consistent radio communications with teams when they are in the field. We observed that teams contacted Command to give routine status updates at least once every hour, and sometimes more frequently if they encountered things that they feel are important to share with Command. Command wanted to ensure that the teams were safe, that they were performing their assigned duties properly, and they wanted to understand what challenges teams faced. Command wanted new information to keep flowing in so that their mental model kept updating. This also kept the teams in touch with Command, in case Command needed to send them new information.

> *"We always want to know where our teams are in the field and how they're doing." – P10 (SAR Manager)*

> *"You're listening to the radio all the time, so you're getting an idea of what teams are encountering, what they're doing." – P4 (SAR Manager)*

> *"For me as a team leader, I'm updating command with what our next move is, if we found the subject, or noticed any along the trail that could impede the other teams. But [we] don't [...] make a big deal out of it. It literally is just to see that you're alive and that everybody is doing [well]." – P5 (Field Team Leader)*

In WSAR responses, there are also times when SAR managers need to inform teams of updated information that is relevant to their tasks. For example, during the mock search, once the crash site location was found by one of the field teams, Command informed all of the other teams via the radio that the site had been found. Command then communicated the location of the site to the teams (as a set of UTM location coordinates). Afterward, Command radioed some of the teams individually (by calling their team number; e.g., *"Team 102, come in."*) and asked them to make their way to the crash site location while being on the lookout for victims along the way. Another example from one of our interview participants:

> *"At some point, [...] we need everybody to know about [new information]. [...] 'Okay, now they're barefoot.' That's important to know if people are looking for tracks, [...] that would be the kind of collective knowledge that would need to be spread out." – P4 (SAR Manager)*

During the mock search, we observed that the communications officer and others around her in the command vehicle would occasionally watch out the windows in front of them to see bits of what is happening outside of the command trailers. This view allowed them to see teams leaving to and returning from their assignments. At one point in time, the personnel at Command watched as a vehicle left on its own:

> *[Vehicle starts to leave the staging area.]*

> ***Operations Manager:*** *Which vehicle was that? [...] Were they asked to go?*

> *[Vehicle goes out to the field on their own, without instruction from Command.]*

> *Operations Manager: Unacceptable!*

As soon as a team or volunteer self deploys, their mental model of what they are doing becomes inconsistent with that of Command. This leaves Command with an incomplete understanding of the operation and the people/resources available, hindering their ability to make proper decisions and keep everyone safe.

> *"If we're not asked to [go] in, then it's not our job to go in. We don't self-deploy. That's management. They have the big picture. We have our focus picture." – P1 (Field Team Leader)*

This even goes so far that Command gets upset when field teams do not properly check in or out when they are supposed to. In the mock search, we observed Command personnel scolding field teams who returned without informing Command of their return, even if workers at Command were able to observe them returning through the windows of the command vehicle.

5.3 Reception Gaps

Remote communication between Command and field teams primarily happened via the radio. We observed that it is the primary way that Command kept in touch with the teams and updated their mental model of the operation, as they were unable to directly observe or communicate with teams face-to-face when deployed. The challenge, however, was that radio reception was often unreliable in the wilderness. Reception gaps in the wilderness contributed to an asymmetry of workers' knowledge of details of the operation, and a breakdown in the shared mental model. As a result of these radio gaps, field teams constantly moved in and out of radio coverage, leading to Command not always having constant communication with the teams. Further, field teams sometimes did not know if they were out of radio range, or even what information they are missing if they were out of range.

> *"[The radio] usually doesn't work well. [...] I can't actually think of a situation where I've been happy with [communications] ever." – P3 (Field Team Leader)*

> *"Very often radio communications [are] quite sketchy. [...] We'll be in areas where we just can't communicate with Command and they can't communicate with us. We have to keep going until we get to a point where we can communicate. That happens all the time out here." – P11 (Field Worker)*

We found that unreliable communication with the teams could increase the time it takes for new information to flow in, leading to Command's mental model of the operation being incomplete. If command did not have the most up-to-date information, they were not always able to make the best decisions given the present situation. Command workers are concerned with receiving as much information from the field as possible in as short of a time as possible and keeping in touch with the field teams to know where they are, how they are, and what they are doing.

> *"What [you're doing as a] SAR manager is [...] trying to make sure that all your teams are proceeding as directed and that everyone's safe. It's nice to know that at all times. When you don't have communication, you make that assumption, but until you've got communication again you don't know that. It's hard when you have dead spots when you can't get in touch with people." – P8 (SAR Manager)*

When Command does not have consistent communications with field teams, they can only make assumptions and predictions of their statuses and progress, based on their last-known status. They can only make an inference or prediction on where they might be, based on their last status update, their given task assignment, known conditions in the field, and any other knowledge they might have in the current moment.

Additionally, information from Command may not always get passed on to all of the necessary teams in the field right away, if there are some teams out of radio range. If a team does not answer the radio right away, Command cannot wait for them to become available, as management must attend to their own duties and respond to incoming communications from other teams.

> *"We were searching for maybe 40 minutes longer than we had to be, because we were in a radio dead zone. We didn't get the update that the person had been found." – P7 (Field Worker)*

Radio gaps also resulted in field teams hearing only parts of a message or conversation. Additionally, they did not always hear messages from everyone if they were in an area where they were within radio range of some teams but not of others.

> *"If we're all on the same channel, you could hear the conversations on that. [...] You don't [always] hear both ends. But if you've got teams that are in your area, [...] you'll hear what they're chatting about. Like [for example] the other day, when the [subject] was located, that team [that located her] was close to us. And so immediately we heard [the team say on the radio]: 'subject responded'." – P1 (Field Team Leader)*

Hearing gaps in radio messages made it difficult to put the radio conversations into context when a field team only heard some of it.

5.4 Communication Prioritization and Discretion

The fact that all radio transmissions were sent and played in the same way meant that all information, whether it was crucial or mundane, was being heard on the other side in the same way. This introduced the potential for the recipient to misunderstand the true priority level or urgency of some message. Not all information may need to be communicated or received in the same way, and indeed sometimes field teams used other communication modalities, both synchronous and asynchronous, to get their message across. These ranged from SMS, picture messaging, and location data. If the information was not urgent, sometimes teams even waited until they returned to Command before sharing it, or they sent it as a message without needing an immediate reply.

As an example, it can be challenging for a field team to get Command to understand the importance of some piece of evidence from the field over the radio:

> *"Often [...] you'll have something that maybe you think is of particular relevance and Command does not seem to be taking it as seriously as you think they should. Very often Command will just tell you to stand by and you don't hear anything." – P6 (Field Worker)*

Workers tried to add priority to radio messages through the use of standard terminology:

> *"We can get priority for a radio transmission via the use of either, depending on severity, 'no duff' or the next step up 'pan pan pan' or the max urgency 'mayday mayday mayday'." – P2 (Field Worker)*

Even when something was important to share with Command, a team may have sometimes needed to wait to send it, as Command might have been too busy to answer in the moment. This could have been due to there being multiple people coming in and out of the command vehicle to exchange information, or multiple field teams wanting to send information to command via the radio at the same time.

> *"Sometimes you might have a situation where there's 10 or 12 teams out on the field, all wanting to communicate with command at the same time." – P6 (Field Worker)*

During the mock search we observed, once the crash site had been located, the radio channel became so overloaded with communications from the field teams that the radio operator could not handle all of the messages by herself. At this point, another member of the management team took on the role of a second radio operator and opened up another radio channel; thus leaving one channel open for teams still searching for subjects, and another open for teams who were extracting subjects that were already found.

To avoid waiting on the radio, interview participants have told us that some agencies allow members to send text messages for less urgent messages or messages that do not need to be read immediately. Some workers coupled these with photos if they needed to show something.

> *"Cell phones may work, if not then [satellite] phones [or the] text-message capabilities of new [satellite-phone] devices." – P2 (Field Worker)*

In other cases, participants told us that teams sometimes wait until they return to Command before giving them some of the information they have collected, to avoid cluttering the radio with chatter. For example, we observed that when a team returns to command, the team leader would give the team's GPS-equipped radio to a manager, who would then upload the GPS record to a computer that would then display the path the team took overlaid on a map of the search area. Over time, this digital map would populate with the paths taken by teams and pins showing key locations, such as where clues were found, thus constructing an information picture of the status and progress of the search.

> *"Teams come back with their GPS. It's uploaded, and you gradually build a map of what teams have been where, and you have your different colours. So the dog team's been through here, we got a hasty team through there, [...]" – P4 (SAR Manager)*

This gave teams an opportunity to explain the route they took, the actions they performed, and the things they found while conducting the in-person debrief with a SAR manager. This was easier to do at Command than while the team was in the field and in the midst of their task 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.

> *"If it's not super urgent [...] it just kind of clutters up the radio chatter trying to tell them where we are. So, we just mark [where the clue is] on our GPS, so when we go back to Command, they can download it." – P3 (Field Team Leader)*

The decision of whether or not to pass some piece of information on to Command was usually left to the discretion of the field team, and most often the team leader. This left open the potential for Command to miss some crucial information they needed, simply because the team did not think it was important to send that information.

In particular, if a team has a less experienced team leader, or even one that does not share the same perspective or knowledge of Command, they might not know what information is important to pass on:

> *"People are human and sometimes maybe it's a team [without] a particularly assertive team leader and they may be like, 'we kind of found this thing but we don't really think it's important,' so they don't push it." – P4 (SAR Manager)*

Lastly, in order for a team to talk to Command on the radio, they must stop what they are doing and find a location where they can get radio connectivity with Command. This often distracts them from their focus on their assigned duties and uses up time that could be better spent searching for the subject.

> *"If you are going and stopping and trying, it takes away [...] There's decreasing returns if you put a whole lot of effort into finding a place where you can get a hold of base and tell them, 'nothing to report'" – P2 (Field Worker)*

For this same reason, SAR managers were also hesitant to page field teams for status updates when they were silent on the radio for a while.

> *"Every time you radio [a field team] ... they're skiing along, they have to stop, they have to take their gloves off, depress the radio [button] ... it slows them down. It's a hindrance to them." – P8 (SAR Manager)*

Some newer radios come equipped with GPS transceivers, which allow command to obtain the location of any field team within radio reach in realtime through the click of a button. This was the case for the mock search we observed. SAR managers have expressed that obtaining information in this way is helpful, given that it comes immediately and updates as frequently as they want it to, and they have also said that it is comforting to know that they can get this information without bothering the field teams.

5.5 Awareness, Distraction, and Level of Detail in the Field

Field workers sometimes want to maintain a shared mental model that is consistent with Command's mental model and higher-level awareness. In particular, field-worker participants have told us that they want workspace awareness of the environment and other field teams' activities, and higher-level situation awareness of the bigger picture of the search status, to the extent that it is relevant to them. They want to know how the bigger-picture of the search is evolving, and they want to know how their actions are contributing to the search response as a whole, so they can understand their impact on the operation and feel less isolated from their team mates. While this is the case, we were told by SAR managers that field workers are supposed to be focused on the in-the-moment demands of the wilderness environment and the search task they were given. This presents an important tension. A team's focus on their assigned duties is beneficial to the operation as a whole (and thus the safety and livelihood of the subject), as it increases the likelihood that they find the subject sooner. On the other hand, remaining aware of one's role within the bigger picture and in relation with everyone else could boost a team's morale, as it could serve as a reminder that the team's focused actions are meaningful to the operation as a whole. A field worker's ability to hear other remote teams may help boost this morale, 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 [20]. Especially in large and difficult searches, WSAR workers often want to know if they are making progress and what is going on elsewhere. This is why they are interested in the radio chatter. But too much of this can become a distraction. In some cases, field teams have even shut off the radio because they were hearing too much radio chatter, and it was hindering their focus.

> *"It depends on the task but sometimes [hearing radio traffic] is obnoxious, where you have to turn the radio down and hopefully remember to turn it back up again." – P3 (Field Team Leader)*

While this is the case, there is also an inherent curiosity about what others are doing, and whether they have found clues:

> *"I know that I'm always listening; like if I'm not busy, say we're just walking down a trail and looking for clues, I'm always interested in what other people are talking about." – P3 (Field Team Leader)*

This curiosity is part nosiness, but also a desire to understand the bigger scope of the search. This could be beneficial in that it could reduce a field team's sense of isolation, boost their morale, and encourage a greater sense of belonging with the entire responding organization (i.e., all personnel who are part of the response). This idea of trying to foster a 'large team' approach is also something that resonated with SAR managers.

> *"I felt that I was always working hard to sort of foster an atmosphere of inclusivity and sharing information. So I'm naturally in favour of as many people knowing the bigger picture as possible." – P10 (SAR Manager)*

Participants told us that this awareness could also have a potential utilitarian purpose. For example, it could allow field teams to know if other teams have found or passed along information that is relevant to them and their duties and allow them to coordinate with other nearby teams if deemed necessary. However, not all SAR managers agreed with this:

> *"[The] right [approach] isn't necessarily to give the field teams more information about where they are in the context of other efforts, but the right level of detail." – P13 (SAR Manager)*

Workers understand this fundamental tension, as the field workers' tasks alternate between moments of boredom (walking through the forest) and times when extreme focus is required (e.g., navigating a gully). Essentially, increased awareness of other field teams could be useful when their work becomes more tightly coupled, when they need to collaborate on something, but less useful when their work is loosely coupled (which is most of the time), when they are focused on their task assignment, even if the increased awareness leads to a boost in morale.

5.6 Inter-Team Communication

While field teams can generally overhear a lot of communication between Command and other teams, protocol prohibits a field team from communicating directly with another field team without going through Command first, even though field teams can generally hear each other on the radio. This is unless they have explicit permission from Command to communicate directly. Participants told us that there are two reasons for this: (1) Command wants to have control and awareness of all information passing through the radio channel, and (2) Command wants to prevent the radio channel from having too much traffic.

> *"[Command doesn't] want to miss anything, and if one team was talking to another team [...] maybe that could happen." – P6 (Field Worker)*

SAR managers also told us that permission to communicate directly with another field team is usually granted for one of two reasons: (1) the team needs to directly coordinate resources or actions with another nearby team, or (2) the team needs to act as a radio relay to Command for another field team that is out of radio range of Command but within radio range of the first team.

> *"[A field team] can ask Command for permission to talk directly to another team, and that would be because they need to share information, but Command is still monitoring and still aware of that information." – P4 (SAR Manager)*

During the simulated operation, we observed one instance of a team requesting permission to talk directly with another team. In this case, it was during the rescue stage of the operation, and one of the teams needed to split into two smaller teams to extract subjects in separate nearby spots. Given that they were deployed with equipment for one team, they needed to coordinate their shared resources via the radio.

One reason that it was beneficial for two field teams to communicate directly with each other in these types of situations is to avoid any loss of information from having messages go through Command first.

> *"If you're running into obstacles out in the field that are hard to get past. [...] it's often useful to communicate directly rather than have a go-between that could distort the message." – P6 (Field Worker)*

The more direct communication is, the more quick, efficient, and clear it is. This is especially important when teams are coordinating with each other or passing along lower-level details. Teams have done this when, for example, they needed to inform a nearby team of hazards, or share navigational instructions. In these cases, it was especially helpful to have local knowledge and guidance from someone who was actually 'out there'.

5.7 Use of Other Remote Communication Modalities

Our analysis revealed that Command needs to fully understand the information that field workers pass to them in order to make good decisions based on it. They also need to understand this information as quickly as possible. When every second counts, delays and misunderstandings can lead to a reduced likelihood that the subject is found alive. There is a potential for other communication modalities and information streams such as pictures and videos to support quicker understanding of information. However, some SAR managers are concerned that bringing in more modalities could introduce the risk of information overload, and it could become too much information for Command to manage and control.

There is opportunity to present information that is rich in visual detail through means such as photos and videos. Just like in firefighting [28], it can be easy to make mistakes in listening and communicating over the radio in WSAR, and these mistakes can have serious consequences. In particular, WSAR workers can easily miss key details or take a long time to describe or understand information that is rich in detail. This becomes more likely given the stressful demands of their work. For example, if a field worker is facing a lot of stress due to environmental demands or the demands of their assigned task, they may not be able to describe some important piece of information in a coherent way. Similarly, if the radio operator at Command is unable to listen to details through the radio as easily due to distractions in the command post, they may easily miss a crucial detail given by a field team.

Examples of information rich in details that can be hard to describe or understand via the radio include the visual properties of clues (e.g., footprints, objects), the geographical layout of a spot (e.g., where trees, rocks, hills, and bodies of water are found), and first-aid information (e.g., the medical state of the subject). Sending images or videos of this type of information could be beneficial.

> *"I could imagine using [pictures or videos] in situations where, if you're in the bush and you're looking for an example helicopter landing zone, if you're looking for a route out, or [...] you can send pictures of the condition people are in." – P9 (Field Worker)*

In recent years, some field workers have begun to send images of clues to SAR managers via SMS/MMS messaging.

> *"We'll obviously be taking pictures with our phones and in the last five or six years we, text messaging is so good I'll just text my SAR manager a picture and he'll be like, 'Yep, that's their footprint' or 'Nope, that's not their foot.'" – P3 (Field Team Leader)*

While pictures and videos could aid field workers in describing the conditions of a scene to Command or help them convey a message, verbal descriptions are still useful in some circumstances; either on their own or coupled with images or videos.

> *"Terrain's usually better described by whoever's out there. It's hard to look at a picture and know what the real situation is." – P8 (SAR Manager)*

While some SAR managers and agencies embrace newer communication channels, they can still lead to potential challenges. For one, adding more channels could make it increasingly challenging to maintain a mental model of the operation, as the workers at Command may have to pay attention to multiple information streams.

> *"I know from being a manager I receive information via voice, text, email and radio already, and synthesizing an operating picture out of those different streams can be very challenging. There are many things competing for my attention during a search." – P13 (SAR Manager)*

In addition to this, adding more styles of communication affects work protocols, requires training in their use, and potentially introduces more points of failure in the operation.

> *"The strength of the current system is that it is durable and fault tolerant, where most digital systems introduce more single points of failure and fragility. A functioning radio, a white board, some pens, and some paper is the basics of a SAR management system. Adding more tools and technology introduces opportunity for failure in the devices, protocols and training of the individuals." – P13 (SAR Manager)*

There are two things that this suggests: (1) aggregating existing information streams before introducing new ones might be more beneficial, and (2) careful consideration should be taken before introducing a new information stream, to determine whether or not it is actually necessary or helpful to the operation.

6 DISCUSSION AND CONCLUSIONS

We now discuss our results and their implications for the design of remote collaboration technologies for WSAR. Our goal is to help readers understand the specific communication contexts and challenges of WSAR workers, so they can understand what design solutions and approaches can begin to address those challenges. We also hope to help direct other researchers in forming research questions for further studying technology use in WSAR distributed collaboration.

While maintaining the shared mental model of the responding agency as a whole is important for a response, there are many challenges unique to WSAR that make this challenging. Some of these are due to technological factors (i.e., communicating over the radio). Others relate to environmental factors, and some relate to current communication and work protocols. We believe that it is worth exploring potential design solutions not only to the challenges that arise due to technological factors, but also to those that are due to environmental, social, and protocol factors. Next, we explore and discuss these challenges and discuss our recommendations for future research and design work in this space. Our recommendations are based on our findings, but any new solutions warrant further validation, especially in settings that are as close to real-world as possible.

6.1 Implicit Communication and Awareness

There are opportunities for technology design to foster and support team awareness, cohesion, and staying in the loop. In particular, there is an opportunity to support implicit communication, coordination, and awareness remotely in addition to explicit communication. Implicit communication and awareness are almost non-existent between field teams and between the field and Command. WSAR workers feel that the background information provided from overhearing radio chatter is sometimes beneficial potentially because it may be helping to fill a gap left by missing implicit awareness and communication. WSAR workers are seeking every bit of higher-level awareness that they can get. Filling this gap could provide a meaningful impact. While we do not yet know what this impact would be, we recommend future design work to explore solutions to providing additional awareness, and study the impacts of these solutions. To illustrate some simple examples, research could explore technologies that allow field workers to see the areas they have covered, the areas their colleagues have covered, a collection of clues their colleagues have found, and messages they have sent over time. Awareness of these things could contribute to the consistency of the shared mental model [10] amongst the workers, which could therefore benefit collaboration and teamwork. As maintaining a shared mental model is one of the key goals of WSAR remote communication, we recommend exploring and testing design solutions that aim to give WSAR workers as much awareness as possible.

WSAR, however, brings about unique challenges in doing this. For one, when a field team is out of radio contact and isolated from everyone else, they simply will not be able to receive updates from other teams. Some technological solutions, like radio repeaters and mesh-networking technologies (e.g., [72]), help minimize this disconnectedness. However, more could still be done to provide WSAR workers with relevant information and awareness while disconnected. For example, it may be worthwhile to explore technologies that present field workers with relevant 'offline' information; i.e., information that is *already there*, and can be presented to the user at the relevant time while out of radio contact, or 'offline'. For example, it could be beneficial to show a field team how much of their assigned areas they have covered, or show Command a prediction (through probability models or artificial intelligence) 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 their given assignments and other factors such as weather. While the information may not be perfectly accurate (e.g., it may be out of date or 'stale'), it could still provide Command workers with more to work with than just receiving nothing. The system could also explicitly tell the user that the information is just a prediction, or even give an indication of how likely it is to be accurate (i.e., a 'confidence' rating). As a similar example on the field side, when field workers are 'offline', technology could give them relevant information such as expected weather changes that are imminent, where other field teams are predicted to be, and predictions of when Command might want an update from them. These are simple 'offline' solutions to maintaining a shared mental model that may be worth exploring in future work.

One thing to note is that 'offline' in this case is not a binary state. A team[1] can be 'completely online' (i.e., able to contact all other teams), 'partially online/offline' (i.e., able to contact some but not all other teams), or 'completely offline' (i.e., not able to contact any other team). Furthermore, the 'severity' of 'online/offline' state depends not only on *how many* other personnel a team is able to contact, but *whom* they are able to contact. For example, being unable to contact Command may be worse than being unable to contact another field team searching the other side of the search area.

[1] *Teams* in this case refers to both field teams and Command.

Even with the importance of a shared mental model, our findings also revealed an important design tension: while field workers often *want* more implicit awareness, they *need to* be focused on their duties. Thus, field teams should not receive too much information that is irrelevant to them and their duties. If this happens, they could quickly become distracted or experience mental overload. When this happens, they could easily become overwhelmed and/or start to miss or ignore important details given to them, and thus start to perform their duties wrong. 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 field teams' contributions to the bigger picture of the search should be presented to the team. This is consistent with the idea from previous work that complete shared mental models are not always necessary for successful collaboration [12], as long as the information shared is up-to-date, consistent, and leads to workers carrying out individual duties in such a way that it helps the organization as a whole push closer to their collective goal. Ideally, a team should be given enough information to carry out their duties properly, keep their spirits up, and understand their contributions to the search response as a whole. Of course, it can be hard to know just how much information is the right amount for field teams. Systems could be designed to easily provide adjustable amounts of information. For example, WSAR managers could select and filter what information should be shared with each field team in software. This could easily be updated at various points in time, depending on the situation. Field teams could similarly have systems that provide them with information where they can select to see more or less, depending on their context.

Additionally, while there could be some benefit to introducing some implicit communication and awareness between field teams (though this should be explored further), we believe that more potential benefit could come from introducing increased implicit awareness between field teams and Command. To some extent this already exists, as Command can observe the GPS locations of teams, look at forms and documentation, and eavesdrop on radio conversations. Though even with all of this, Command still needs to put a lot of effort into communicating explicitly with the field teams to get an updated picture of their statuses. Much of this information still does not come automatically or implicitly. Gaps in radio coverage worsen this problem. By allowing for more status information from field teams to come in automatically, this could save time on Command's part and allow them to put more attention toward other activities. As a simple example, it could be worth it to explore 360° cameras worn by field workers that automatically take and send geotagged photos of their surroundings to Command, where they are then displayed within digital maps of the search terrain. Photos could be shared either periodically (e.g., every 10 minutes) or during key events such as when they have reached a certain location or when they are stopped for a long time. Software could allow WSAR managers to 'scroll through' time and see how the content and location of the photos change over time.

6.2 Communication Modalities and Information Streams

Based on our findings, we believe that WSAR workers, teams, and agencies could benefit from having multiple modalities of communication and information sharing at their disposal, each useful for certain situations (e.g., photos may be useful for describing clues, maps may be useful for describing locations, and text may be useful for quick status updates). Currently, however, a lot of (though not all) remote communication happens via the radio, which does not do well at presenting different types of information in useful ways, at useful times, or giving it the necessary prioritization.

Information Presentation, Prioritization, and Classification. One of the biggest challenges we found is that there is a lot of information coming in from the field, and SAR managers have to bring all of this together and make sense of it. While there could be a potential benefit to introducing other channels such as video, bringing in more information streams introduces a greater risk of mental overload. Before focusing on introducing more channels, designers should first focus on aggregating the existing channels together and presenting the information in a simplified way to the necessary people. Such a system could work, for example, as a shared communication workspace. In addition, part of the task of sorting through and presenting information is relatively mundane, and could likely be automated, thus saving time and allowing workers to attend to more important duties.

A system that aggregates information streams could be designed to support multiple communication modalities, allow workers to see the statuses of other workers and teams, allow Command to refer back to previously-collected information, and allow the agency to keep a record of everything that happens, for liability purposes. While such a system could be helpful in WSAR, it must be designed so that it is easy to search and sort through this information. If the workspace is designed like a flat-priority system, it may become too easy for important information to get lost in a sea of noise, as it often does in collaboration platforms like Slack [9,68]. 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. As an example, if a manager at Command queries a task assignment number, they may be interested in seeing the rough search path taken for the assignment and the area covered by it. If a field team leader queries the same assignment number, they may be interested in seeing details on the search techniques to carry out, the landmarks in the field to watch out for, and the equipment needed. Furthermore, a field worker may be interested in seeing a search path in relation to their own first-person view of the environment, whereas a manager at Command might be interested in seeing it overlaid on an overhead map.

Asynchronous Communication and Information Aggregation. Our findings indicate that, as a result of radio reception gaps, information can propagate slowly. A lot of the information exchange between field teams and Command happens before and after task assignments, due to both the unreliable reception in the field and the fact that field teams are heavily focused on their tasks while in the field. While it has its downsides, lack of realtime communications can also sometimes be beneficial for field teams, as it allows them to focus on the task of searching and collecting information. From this, we infer there is potential opportunity for asynchronous communication and information sharing that should not be ignored in future explorations of WSAR remote collaboration.

As an example, a field team may want to share some piece of information with Command, but they do not need them to view or respond to it immediately. A team outside of radio coverage could queue up a message to Command that would send as soon as they regain contact with Command. Additionally, a team would not have to wait for Command to become available before sending a message to them. A team could send a less-urgent message to Command quickly, then carry on with their duties. WSAR workers have cited this as a reason for sending and receiving text messages and photos.

Focus and Distraction-Free Communication in the Field. Given the mental and physical demands that field workers face, communications should be as simple, minimal, quick, and distraction-free as possible for them. Technology should provide minimal distractions from field workers' immediate surroundings, allow them to communicate hands-free if possible, minimize the amount of time they need to spend sending and receiving messages, allow them to answer less-important messages when they are less busy, and allow them to focus on listening and being on the lookout for the subject. Asynchronous communication, as described above, helps with this, allowing field workers to focus on their duties and respond when they are better able to. In terms of synchronous collaboration, hands-free technologies such as wearable cameras (e.g., [45,63]), wearable augmented reality (e.g., [44,61]), and drones for video communication (e.g., [40]) show potential promise.

6.4 Communication 'Dead Zones'

Lastly, even with the implementation of multiple design solutions to WSAR communication challenges, radio-reception 'dead zones' are still an issue in WSAR. One issue that workers face related to these dead zones is that they generally do not know if and when they are in one. WSAR workers do not know when they have entered a dead zone, nor when they have exited it. In addition, neither Command nor other teams generally know if a specific team is in a dead zone. One possible solution, stemming from the principle of seamful design [14,15] is to allow field teams to see (e.g., as a simple status icon) whether or not they are able to contact Command. Furthermore, if communication with other field teams is permitted, it could notify the team which other teams they can communicate with. Remote collaboration tools could reveal on a map where radio dead zones are located (similar to [7]) and notify when field teams are in one and when they are about to enter one. This could allow a field team to plan for when they will enter a dead zone and adjust their work activities based around this. It could also allow Command to know when a team is in a dead zone or when they are about to enter one, so they could prepare in advance of this. Rather than just being seen as a challenge, dead zones could also be seen as opportunities for field teams to focus on their search task and collect information without distraction. When a team leaves a dead zone, a system could remind them to get in touch with Command again.

Furthermore, while not directly related to usability, mesh-networking technologies and communication platforms (such as [72]) are seeing increasing adoption in emergency domains. In the context of WSAR, new communication platforms could support automatic information collection and transmission between field teams' radio antennae, ultimately reaching Command. Such technologies could seamfully reveal, for example, who a team can reach contact with in a mesh network, if Command has received or read their message, or the last confirmed time that Command was able to observe the team's status or location. We see opportunity for exploration of this in future work.

7 LIMITATIONS AND FUTURE WORK

Overall, our study opened up the design space for WSAR distributed collaboration, outlining the information-sharing activities and challenges of WSAR workers and providing initial thoughts on the opportunities for new and emerging technologies and communication modalities to begin to address these challenges. This will be particularly beneficial for WSAR workers around the world, many of whom are volunteers, as well as for outdoor enthusiasts and anyone who works in wilderness areas who may ever need WSAR services.

Beyond the design considerations we mentioned above, we also recommend that future work look into other WSAR contexts beyond just those of Western Canada, as differences in contexts could potentially reveal newer insights. Most of our participants were from agencies near small mountain towns. Some were from more remote regions that see fewer tourists, and a few were from agencies near a large metropolitan city or near towns that see many tourists engaging in outdoor activities. Moreover, while WSAR protocols vary slightly across Western countries, they may differ quite widely in non-Western contexts.

The demographics of our study were largely limited to older men (average age of about 50 years), given that this is the demographic that is prevalent in WSAR in Canada. Studying more women or younger WSAR members who are more technology literate may reveal different communication and technology-use patterns. Similarly, given that most of the SAR workers in our study were trained in the same way (under the same set of guidelines), their mindsets about how things should be done in WSAR may have been limited as a result of this. Thus, we recommend future work include a broader set of participants, and also take into account those who could participate in WSAR in the future (rather than just those who participate in it now).

Lastly, our observation was centred around a single mock-search exercise based on a scenario involving a search for multiple missing subjects. While this scenario was designed to be complex, to train WSAR workers in multiple aspects of their work and to expose workers to a variety of things they could encounter in a real operation, we recognize that this does not cover the complete scope of possible WSAR incidents. Though we complement our observation findings with interview responses from WSAR workers playing a variety of roles with varied experience and skill levels, we recommend future studies in this space, including validations of design solutions, explore other types of WSAR scenarios; e.g., usage in different types of environments, rescue-only operations, and searches for single subjects.

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