Building a Birds Eye View: Collaborative Work in Disaster Response

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ABSTRACT

Command and control environments ranging from transport control rooms to disaster response have long been of interest to HCI and CSCW as rich sites of interactive technology use embedded in work practice. Drawing on our engagement with disaster response teams, including ethnography of their training work, we unpack the ways in which situational uncertainty is managed while a shared operational 'picture' is constituted through various practices around tabletop work. Our analysis reveals how this picture is collaboratively assembled as a socially shared object and displayed by drawing on digital and physical resources. Accordingly, we provide a range of principles implicated by our study that guide the design of systems augmenting and enriching disaster response work practices. In turn, we propose the *Augmented Bird Table* to illustrate how our principles can be implemented to support tabletop work.

Author Keywords

Tabletop; disaster response; ethnography; collaboration; situation awareness; uncertainty; crisis informatics

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Command and control environments and operational settings have long been of interest to HCI—and particularly CSCW—as rich sites of interactive technology use embedded in work practice [13,15,25,40]. Shared wall displays and tabletop surfaces are a common feature of many of these settings and these are used to support situational awareness, decision-making, and collaboration amongst teams [30,37]. This has not gone unnoticed by HCI and the ITS (Interactive Tabletops and Surfaces) communities as an opportunity for deploying the considerable body of research into the natural interaction practices [32,44], interaction techniques [22,36] and technical innovations [1,17,20]. Consequently, designing for disaster response settings has gained increasing currency in HCI [5,7,27,38]. Accordingly, there are a number of recent examples of interactive surfaces being developed that draw their motivation from the need for situational awareness in emergency response situations [2,23,24,26,28].

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We complement these interests by focusing on the everyday practices involved in command and control in disaster response. We are particularly interested in unpacking the ways in which the responders cope with contingencies inherent to these settings. Surprisingly, we find this a domain that has received little attention, despite its acknowledgement by disaster response professionals [16]. In order to examine the practical nature of these settings we embedded with Rescue Global, a disaster response organisation in a 2-week long Search and Rescue (SAR) training exercise. We wish to balance the emergence of new capabilities with an understanding of how *existing* practices are actually constituted as a matter of disaster responders' work and the impact this might have for future technologies.

The first contribution of this paper is a study of the practical reasoning and action of disaster responders' work practices that surface ***management of uncertainty***. To do so we focus our study on responders' work around a 'bird table'—an analogue tabletop. We highlight how *four different uncertainties* impinge upon team members' interactions: 1) uncertainty around infrastructures and logistics (e.g., with implications for mobility and form factor); 2) uncertainty of the actual availability of resources to construct an operational picture; 3) uncertainty as to whether the equipment remains operational over time; and 4) uncertain validity of the information drawn upon to construct the operational picture.

Drawing on our first contribution, our second is a set of principles for design of technologies in uncertain environments. These principles can be summarised as a recommendation broadly to *augment and enrich* existing sites of the operational picture (e.g., the tabletop). Given the emphasis on collaborative interaction around shared surfaces and the growing interest in disaster response as an application domain for interactive tabletops we illustrate this by reference to digital, interactive tabletop design for disaster response.

In the following sections we firstly cover in greater detail the literature at the intersection of disaster response settings and interactive tabletops. We then present our study, providing an overview of the setting followed by a series of data fragments that highlight aspects of uncertainty in disaster responders' work.

RELATED WORK

We briefly review research on collaboration in command-and-control settings. We then focus on research to support hybrid physical-digital work, and review tabletop systems, particularly to support disaster response.

Studies of Command and Control Settings

Command-and-control settings have been a mainstay of CSCW research focusing of how operators manage and control safety-critical systems. This paper aligns with the long-standing tradition to study these complex settings to identify implications for technology support. Heath and Luff's study of London Underground shows for example how co-orientation among operators is critical in this "multimedia environment" [13].

Tolcher [37] showed in his PhD thesis how military planning around bird table maps is accomplished through collaboratively developing and analysing courses of actions. Tolcher's work is particularly relevant to our study, in that there is significant overlap between the planning process employed by Rescue Global and the UK military Standard Operating Procedures (SOP).

Collaborating across the physical-digital divide

Related to the prevalence of paper resources (especially maps) in our study, MacKay's work on the use of flight strips in air traffic control has highlighted the kind of physical interaction afforded by paper [25], also relating more broadly to research on the role of paper in knowledge work collaboration [33].

The challenge to overcome what might be termed the *physical-digital divide* in tabletop work has driven much technical innovation and research (cf. [14]). Often this work has attempted to combine the advantages of paper and electronic documents [42], including hybrid interaction techniques [22], interaction frameworks for pen-and-paper user interfaces [36], and integrated prototypes for collaborative annotating, linking and tagging digital and printed documents [35].

Tabletop systems for situational awareness

More recently, research has emerged that focuses on situational awareness in incident management as an important application domain for tabletop systems. Most of these systems are implemented on large multi-touch tables with a GIS base system, and allow for example the browsing and annotating of maps [28], spatial information overlays [24], automatic placement of annotations to avoid occlusion [19], and integration of digital pens for precise interactions [9]. While most of these systems are aimed at supporting map-based situation assessment and planning of operations, some are specifically designed to support simulation of disaster scenarios for training purposes [4,23]. However, the work has in common that it assumes a relatively *permanent* control room or portable incident vehicle in which bulky hardware is installed and remains set up. Yet, in the setting we studied, a *temporary* control room was set up for not much longer than the duration of the operation. This fundamental difference already anticipates substantially different design implications for this setting.

Given the current role of shared surfaces in incident response the capabilities offered by interactive surfaces are obviously appealing. However, the challenge remains as to the extent to which these might actually mesh with work practice. Although we have seen some engagement with practitioners include the development of guidelines [2], interview with experts [9], and a user-centred design process with the German Technical Relief agency (THW) [26], there has been little emphasis in understanding the nature of the setting into which these technologies will be deployed.

At present we have little insight into how responders socially organise their work. Understanding the social organisation of work has been central to grounding the design of interactive tabletops. Scott et al. for example found that people structure the (analogue) table space into 'personal', 'group' and 'storage territories' [32]. Similarly, research showing that task time pressure has an observable impact on group dynamics [44] is relevant in disaster response. Insights that emerge from our study relate to ways in which one of the fundamental challenges of any disaster is dealt with: the inherent uncertainty of the situation [18].

STUDYING DISASTER RESPONDERS' WORK

Disaster response may be understood as a stage in the broader disaster management cycle, which includes prevention, preparedness, response and recovery/relief [41]. The response includes activities such as Search and Rescue, medical support, reconnaissance to assess the situation, and providing assistance to restore infrastructure.

Rescue Global (RG) is a disaster response organisation. They are a UK charity and a US not-for-profit headquartered in London, UK. Their remit is to provide "*immediate crisis and disaster reconnaissance ability, delivering accurate and timely information and risk data, as well as performing emergency search and rescue operations where needed to save life.*" [30]. RG has adopted a framework of procedures that implements ISO 9001 Quality Management (QM) principles, which commits RG for example to conduct risk assessments and to record decisions for accountability purposes. This has implications on the ways in which missions are planned and carried out (the focus of our field work).

RG's organisational structure represents a typical hierarchy found in emergency services (cf. [39]), termed Gold, Silver and Bronze. Gold denotes the strategic lead, which is associated with RG's senior officers (often referred to as the 'head shed') and the headquarters in London, Silver is the tactical lead, which is 'spun up' for mission planning, both to assess feasibility of deployments and when actually deployed onsite. Bronze refers to the operational level, in which 'Pathfinders' (field responders) carry out operations 'on the ground' supported by Silver command [29]. RG's core staff consists of around 20 highly specialised experts and admin support, many of whom have had prior careers in the military, and emergency and first response services.

As part of our collaboration with RG we were invited to accompany RG to a large training exercise—"Angel Thunder"—in order to observe aspects of their work practice (albeit in a training context) in the field so as to inform technology design. Angel Thunder (AT) is a yearly inter-agency two-week Search and Rescue (SAR) event involving military, and personnel recovery agencies mainly from the US, but also from many nations around the world. Continual training, including in skills outside individual member's area of expertise is part of RG's strategy. The goal is that staff can flexibly take on multiple roles. While RG staff engaged in many different activities during the AT period, we focus in this paper on one particular three-day exercise, "Operation Praesidio", as it presented the most comprehensive training operation.

Our specific interest within this is in unpacking a key feature of disaster response work: the 'Commonly Recognised Information Picture', or 'CRIP' [18]. This is a domain-specific term referring to situational awareness held in common by the members of involved disaster response organisations. *Just how* the CRIP was constructed as a social object—preserving uncertainty and constituted of formal planning, various digital and non-digital resources, and tabletop representations—is subject of our analysis.

Our approach

We conducted an ethnographic study so as to inform the design of technology to support RG's work [8]. To this end we collected field notes, photos, video recordings, and audio, and copies of documents. We present our findings, particularly drawing on video data to focus on the interactional accomplishment of activities [12], and from back briefing this analysis to RG about 2 months after the operation (a 'member checking' meeting). Our analytic orientation is informed by ethnomethodology; which here means we investigate the practical action and reasoning of RG staff. During our ethnography, RG were practicing a new planning procedure—"7 Questions"—which had the advantage for us as ethnographers that it enhanced the observability of RG staffs' reasoning around the production of the CRIP.

The RG team attending the broader AT exercise comprised 13 members. Five members were senior 'head shed' (Gold/Silver), Six members were junior (Silver/Bronze), and two admin staff.

Silver (tactical command-and-control) was set up close to a small municipal airport with skydiving facilities associated with AT, in a large room (approx. 538 sq ft / 50 m^2) with good amenities and infrastructure, including power, Ethernet, air conditioning, a fridge, tables, chairs, whiteboards, flipcharts etc. RG brought and set up their own office and communications equipment. Areas of the room were designated to certain activities and roles.

The training exercise context: 'Operation Praesidio'

One of RG's main internal learning and training objectives for participating in AT and specifically deployed in Operation Praesidio was the "7 Questions" (7Q) planning procedure. To this end, one of RG's senior officers—Eric—who was familiar with the planning procedure acted as a 'trainer' during the exercise. The 7 Questions, as a process-oriented planning procedure, has been linked to good response practices in uncertain events [21]. We present the 7Q here so as to contextualise subsequent aspects of the ethnographic work we describe later. Each of the 7Q is associated to tasks, resources used, outputs and milestones achieved (see Table 1).

Tactical mission planning procedures such as the 7Q are aimed at supporting members in aligning information about the situation (environment, structures, hazards, people, third parties) to the organisation's own capabilities and resources to deliver a certain kind of operation in a way that makes optimal use of resources, whilst managing uncertainty (e.g., being risk averse) at the same time. We found that in practice tasks in the 7Q planning procedure may be done concurrently in anticipation of certain outcomes. As the outputs of previous stages are used for further planning, they remain open for scrutiny and refinement.

Operation Praesidio itself proceeded in the following way. On the morning of Day 1, Eric briefed the designated Incident Commander (IC) to conduct a reconnaissance operation ('recce') on the third day, and that the team is to progress to complete Q5 at the end of Day 1. The Incident Commander then delivers the following scenario as a 'Request Order' that spins up tactical planning (Silver):

The international community plans to evacuate the town of Coolidge (~3,000 inhabitants) to save them from an imminent threat posed by hostile forces via air transport from the nearby disused Municipal Airport. RG has been requested to provide early reconnaissance to enable planning and execution of the evacuation. Specific tasks for the recce include:

- **roads** in and out of the town,
- **holding and camping areas** (for people and vehicles),
- **water** sources to enable life support of camps,
- **alternate landing sites** (for helicopters and planes).

Question	Task(s)	Resources	Output(s)	Milestone
1. What is the situation?	Terrain analysis, risk mngmt	Digital + paper tools, maps, info	Situation Overlay (SO)	Team issued notice to move
2. What action has been requested?	Requirements analysis	Request order	Confirmation order	Client back briefed
3. What effects are required?	Define activities	SO + Request	CO's intent and endstate	Endstate defined
4. Where can the effect be best achieved?	Integration of SO and CO's intent	SO + intent	Decision Support Overlay (DSO)	Areas of interest defined
5. What resources are required?	Resource allocation, risk mngmt	SO + intent + DSO	Decision Support Matrix (DSM)	Warning Order
6. What coordination is required?	Sequencing, 3rd party liaison	DSM	Synchronisation matrix	Task complete
7. What control measures are required?	Comms procedure, risk mngmt	DSM	Comms plan, Risk analysis	Go/no go brief

Table 1. The "7 Questions" (7Q) planning procedure.

After delivering the scenario, the IC (Dom, Pathfinder team leader with a background in alpine mountaineering) handed out individual taskings to begin the planning process. Bill, (Pathfinder with military experience) is tasked with geography, terrain analysis, roads in/out, and water. Clive, the RG information manager is to look at the airport, potential campsites, holding areas, food and water storage, and power. Andy (pilot) is to provide a detailed weather report, and identify potential alternate landing zones.

BUILDING THE CRIP

A key goal for the RG team at the Operation Praesidio exercise was the construction of the Commonly Recognised Information Picture. The primary artefact around which the CRIP's construction is shared and (literally) made visible amongst the team is the **bird table**, a large tabletop surface located in the centre of the main planning area of the Silver command-and-control operations room. The physical centrality of the bird table makes it a natural coordination point for the on-going work observable in face-to-face discussions, annotating acetates placed on paper maps, and digital work on laptops placed on the bird table, and on surrounding desks.

In order to understand how the CRIP is co-constructed, displayed, and refined on and around the bird table, we turn to three aspects of its construction and use: first, the mixed resources drawn together to constitute the CRIP itself; second, the introduction of uncertainty into the transferral of resources to the bird table; and third, its resolution in decision making processes around the bird table. As part of this we must also introduce the bird table itself.

Working up the CRIP: Digital and physical resources

The members of Silver went about constructing and making the CRIP visible on the bird table in what we might term as a 'mixed media' environment.

The bird table: Paper maps and acetate overlays

The central feature of the bird table is a set of maps and overlays that are used to highlight information relevant to the mission. The bird table's map is overlaid with two separate layers: a 'Situation Overlay' and a 'Decision Support

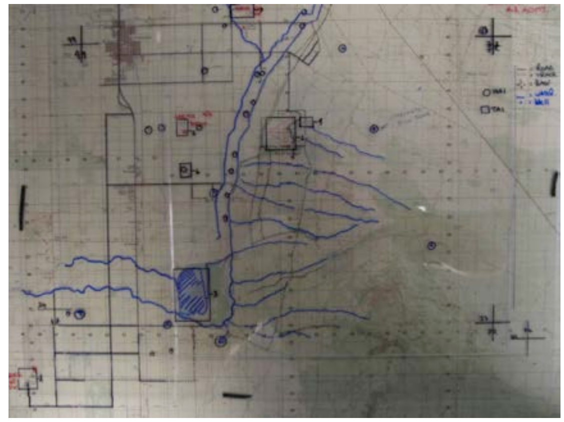

Figure 1. Bird table map with the Situation Overlay (highlights relevant roads, water, wells, base, etc.), and the Decision Support Overlay (highlights areas of interest).

Overlay'. These are both practically realised through annotating an acetate sheet that is then placed over the map, thus offering a set of removable annotations (see Figure 1). The Situation Overlay is constructed by highlighting geographical features that are relevant to the initial Request Order, e.g., roads for the evacuation and water features such as a reservoir, wells, rivers, and canals.

Consider the following fragment, in which the Commanding Officer (CO), Fred—who had been busy during the Request Order briefing—delivers his 'intent' (Q3, see table 1) to the IC (who is in the process of constructing the Situation Overlay), after showing a visitor around Silver, and thereby briefs his team on the mission goals.

Figure 2. Fragment 1 a) CO delivering his intent (mission goals); b) pointing at airport on Situation Overlay map.

```
Fred: Reassure that population ((points at town on map,
  fig. 2a)), prepare them to move within three weeks.
  Check at least 2 routes from there to this location
  ((traces routes to airport)), Secure this location
  ((points at airport, fig. 2b)) with an airborne inser-
  tion of pathfinders because assume the roads aren't
  clear. Pathfinders when they parachuted in to secure
  this area ((points at airport)) to allow the infillers
  of Silver. When Silver is here them to then brief the
  Pathfinders to do reconnaissance of this area ((points
  at town)) and the hill area which is 450 metres that
  direction ((points off map)) to do water samples.
```

Fragment 1 shows how the CO was able to orientate to the on-going construction of the Situation Overlay on the bird table and deliver his intent 'off the cuff', despite him being busy and absent up to this point.

The Decision Support Overlay is then constructed to 'integrate' the relevant mission goals (i.e., the CO's intent) with the Situation Overlay. In effect, the Decision Support Overlay further highlights specific areas of interest that are relevant to the mission goals. The areas of interest represent potential candidate site for 'recces', operations in which Pathfinder team(s) investigate on site, in this case to find (access to) water sources and test its potability. In a sense, it represents a further filter on the more general geographic information presented on the Situation Overlay. Figure 1 shows the map with both the Situation Overlay and the Decision Support Overlay fully annotated after Q4.

The bird table map and overlays are a key shared resource for RG team members to read and align to the progress in the 7Q planning procedure; it forms an accessible, common frame of reference, including for members more peripheral to its ongoing construction (cf. the CO delivering the intent). The use of the acetate sheets enables the team to simply and flexibly add and remove annotations to the map, and incrementally render the various resources (particularly the Request Order, the CO's intent) to a shared resource.

The bird table: Use of digital tools

A core part of what gets rendered to the bird table is resourced via digital means. Digital tools were routinely used by RG staff to further enrich the CRIP. For example, the pilot used Google Earth to study satellite imagery of the surrounding area in his task to find alternate landing zones (ALZs). This involved assessing the condition of the ground, measuring the length and width of potential strips (which has implications on which kinds of aircraft can safely land), finding distances and routes to base (Silver), and retrieving geo-coordinates. Having been asked what he was doing, he offered the following account.

Figure 3. Fragment 2 a) measuring distance to an alternate landing zone; b) copying info to notebook.

```
Andy: In all these operations, what we do is we try and
  find as many landable airstrips, helipads, flat areas
  that we can. (...) And normally there are alternatives.
  Google Earth is a great little tool for that. And like
  we look here ((zooms in)), and we see within ((selects
  'ruler' tool)) a relatively short distance (1.0) find
  out how short ((selects scale)) in miles. Right so just
  three-and-a-half miles away we have something ((taps on
  location on screen, fig. 3a)). We don't know how usable
  it is, but we can work it out by zooming in ((zooms
  in)). And then you can see, it's reasonably long but
  it's incredibly narrow. Won't be good enough for big
  transport, but we could get something smaller in like
  the King Air. So I'm just- basically measuring (.) air-
  fields and plotting them on the map at this stage so we
  can use it for planning later on. ((measures length))
  See that's 800 metres. That's kind of usable for us
  ((takes a note in notebook, fig. 3b)).
```

The pilot proceeded to save the location, compile the information into a (Word) document, and email it to admin and the Incident Commander. The landing zones were then transcribed onto the Situation Overlay acetate, indexing the availability of further information on the matter.

The use of digital tools is not limited to planning: they were also used extensively to communicate with Pathfinders and track their locations. Consider the following fragment from Day 3, in which Clive uses IncaX Geocaster on a laptop to track the Pathfinders, and transcribes their locations to the Decision Support Overlay on the bird table. As the Pathfinders are en route to do a 'confirmatory recce' of the water reservoir (which we return to shortly), Eric walks up and stands next to Clive, looking at his screen.

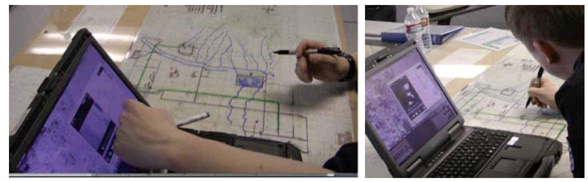

Figure 4. Fragment 3 a) pointing out travel direction on tracking software UI; b) transcribing tracking to map.

```
Eric: Have they turned south yet?
Clive: Yep. See ((points pen downwards, fig 4a)) that's
  the direction they're looking in (...). So they'll be
  joining the 87 in erm (1.0) a very short time. (...) Do
  you see what I mean ((pointing at screen)), they'll be
  joining this ((traces route on acetate)). (...) So
  they're now driving south on 87 (2.0) At approximately
  55 miles per hour.
Eric: Northing?
Clive: Northing would be ((leans in to screen)) 45th
  northing. Just crossed the 45th northing. ((looks at
  watch, transcribes tracking point as "[time]:IncaX" to
  map, fig 4b)).
```

Some time later Clive comments on this process, "Even if you loose comms you should be able to estimate where they are. And with an increasing degree of uncertainty as they may have taken different routes and stuff".

The fragment shows how Clive uses the tracking software to offer to Eric the Pathfinders' current location, translating this location first by pointing, and then transcribing it to the acetate. The annotation "IncaX" points to the provenance of the track point, indexing its information source. Slightly later on Clive comments on the 'boundary' of the training exercise, noting that information on the Pathfinders' current location could become increasingly uncertain in particular circumstances, yet various methods could be employed to mitigate this. This point anticipates an informational uncertainty in the resourcing process when building the CRIP, which we will return to shortly.

In summary, then, we have shown how the CRIP is constructed and maintained or updated by drawing on a mix of physical and digital resources. This can be thought of as a 'sources and sinks' arrangement. The annotations on the acetates serve as indices of the 'sources' (e.g., IncaX in Fragment 3), and 'sinks' of information (e.g., the pilot's tacit domain knowledge and his further documentation in Fragment 2). We also have seen how the bird table's physical accessibility enables peripheral members to readily engage and contribute to building the CRIP (Fragment 1).

Uncertainty in CRIP resources

Working in a mixed digital-physical information environment, members routinely transfer information resources across the 'seams' from one medium to the next. A complicating factor is that secondary—i.e., unconfirmed and therefore uncertain—information may be inconsistent. The work of transfer not only preserves this uncertainty when translating across seams, but also offers a moment of reflection on the veracity of the information being added / shared.

Consider the following fragment, drawn from the afternoon of Day 2. Three team members are in the process of discussing the risk assessment for Q7 (see Figure 5). Bill brings up the issue of the water reservoir. This has been highlighted on the Situation Overlay during the Terrain Analysis (Q1) as a potential water source (see fig. 1), but when Andy (the pilot) used Google Earth on the previous day to identify landing zones on satellite imagery, he discovered that "the reservoir is a forest now".

Bill [left]: Erm. We need to (.) redo this. ((points at water reservoir, fig. 5a)) (...)
Dom: Why?
Bill: Because it's suggested we are not doing this (1.0) ((retracing reservoir outline with finger)) any more (...) we don't need to highlight it. In fact we need to cross it out ((makes crossing-out gesture)) and make it green ((laughs)).
Andy: We left it in deliberately to show the water supply ((taps on reservoir)) ( ) as a point of note.

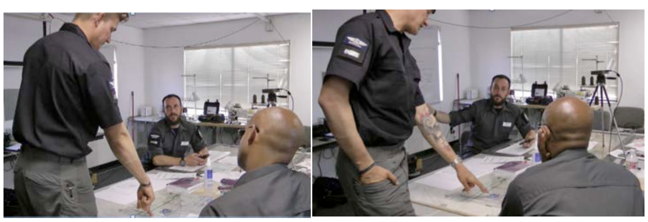

Figure 5. Fragment 4 a) pointing at the contested water reservoir; b) Dom suggesting to keep it as a point of note.

Dom: Yeah.
Bill: ( ) Google Earth. More updated imagery?
Dom: Exactly. And hopefully that will just lead to the whole can we have Falcon View please.
Andy: Well in this case we found it and then found out that it wasn't the case.
Bill: We do in fact have Google Earth? Real world and scenario yes?
Dom: ((nods))
Andy: Ya-ya.
Bill: So we've already (...) done (...) our map recon our most basic recon that we always do before we go anywhere and found that that's ((points at reservoir)) not there. So. ((makes crossing out gesture))
Dom: ((tuts, nods))
Andy: Yah. We made a point of note already ( ) so you can get rid of it as well. Well. ((shrugs))
Bill: We are in fact briefing this right? Or no.
Dom: We are. And I was gonna put that into the briefing-that (...) when doing lat longs (...) and looking further afield than just the airfield we found this on Google Earth. Therefore point of note (.) we need to get some really up to date current maps ((talk omitted))
Bill: So you wanna keep this on there ((points at reservoir, fig. 5b))?
Dom: Yeah. ((talk omitted))

Bill initiates this dialogue by suggesting to change the highlight of the reservoir on the Situation Overlay from signifying a body of water to land ("we need to redo this (...) we don't need to highlight it (...) we need to cross it out and make it green"). Andy points out (and Dom agrees) that this was left on deliberately as a 'point of note', which also refers to a specific kind of item in the risk/QM management procedure. Google Earth is then brought up, the information source that is seen to refute the existence of the water reservoir. The way Dom responds anticipates a potential outcome of relaying this point of note to the 'head shed', that this might emphasise the need for a specific mapping application ("hopefully that will just lead to the whole can we have Falcon View please"). Andy then points out that ("we found it and then found out that it wasn't the case") as if to offer an account of how the refutation was arrived at, perhaps in anticipation of the briefing. Bill then raises the question of the training exercise 'boundaries', and whether Google Earth is 'permitted' (which his teammates confirm). However, Bill reiterates the point that their initial map recon revealed that the reservoir is "not there", and concludes by repeating the 'crossing-out' gesture. Dom and Andy's responses do not indicate their full agreement. Bill's question whether this will be briefed prompts Dom to anticipate what he might offer when briefing the 'head shed' on the following day ("when doing lat longs (...)we found this on Google Earth. Therefore point of note we need to get some really up to date current maps."). Subsequently Dom and Bill agree to keep the reservoir as is (not shown in this transcript).

The interaction in Fragment 4 illustrates how members resolve the challenge of dealing with conflicting information. While conferring an epistemic authority to Google Earth, nevertheless, the team achieves a form of 'resolution' precisely by *postponing resolution* purposefully. They agree to 'brief it' as a 'point of note' to the higher ups, rather than by acting on it directly, here and now, which in this instance means erasing the reservoir from the Situation Overlay. By doing this postponement, the original conflict is preserved, and indicates in turn their preference for actively *preserving* conflict and therefore the essential uncertainty of the informational resources they draw upon.

The second point we note is that the team is continually and reflexively working with reference to the boundaries of the training scenario (e.g., whether Google Earth is 'allowed'). This is important because it helps decide which conflicts or uncertainties are to be preserved and which are irrelevant.

Resolution: Deciding 'what to do'

The previous fragment showed how secondary (i.e., 'unverified') information results in uncertainty in the CRIP. The resolution of this can be achieved either by verification from a trusted source, or conducting missions to investigate the situation on the ground. In the case of the reservoir, the following fragment from Day 3 shows how Dom (the IC), the CO and Eric achieve such a resolution.

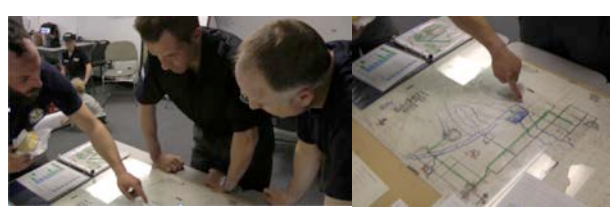

Figure 6. Fragment 5 a) Dom briefing senior officers; b) pointing at secondary water source close by reservoir.

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Dom: We left this on as part of (.) a reference for when
  we do the debrief. We got excited about this ((points
  at reservoir – fig. 6a)) feeding all of this stuff
  here. This looked cool. On later inspection with Google
  Earth as were trying to get lat longs we found that
  this is just a field ( ).
Eric: Let's do a confirmatory recce.
Fred: Ya. That's good idea. That's a nice location. (...)
  That's a target.
Dom: But we know from Google Earth (.) that it's not.
Fred: Yea but we might assume that we don't have that
  connectivity.
Eric: Also Google Earth changes as well.
Dom: Yea.
Fred: And if you didn't have that connectivity anyway
  you'd have to go physically eyes on (...) Okay so have
  that as a confirmatory recce is it usable ( ).
Eric: ((nods)) or there might be pockets of water in the
  area ( ).
Dom: Yea. We know that there's- (1.0) ((points at well
  below reservoir, fig. 6b)) Well we don't know (.) but
  there might be.
Eric: Well that's it. Seek out a- seek out a water sup-
  ply. If you go there ((points at reservoir)) and
  there's nothing there then there's your secondary
  ((points at well)).
```

Here Dom offers his conclusion that the reservoir `"is just a field"`, embedded within his account of the work process through which he arrived at this conclusion. Thus, map annotations are indexical to the tacit part of the CRIP developed through collaboration earlier. Immediately after the end of Dom's turn (i.e., his briefing to the senior officers), Eric states `"do a confirmatory recce"`, with which the CO agrees. As Dom interjects `"But we know from Google Earth that it's not"`, Fred points to the boundaries of the training scenario as a way of introducing uncertainty over available infrastructure (`"we might assume that we don't have that connectivity"`). Eric builds on Fred's utterance by introducing a different kind of uncertainty around the information presented by Google Earth, i.e., that it `"changes"`. Fred then returns to his earlier point on infrastructural uncertainty to establish grounds for Eric's idea of a `"confirmatory recce"`. By way of reinforcing what the projected work of the recce might do, Eric hypothesises `"pockets of water in the area"`. This culminates in Dom *repairing* his utterance: from "we know that" to "we don't know but there might be". Dom builds the emerging sense of informational uncertainty into his talk.

Two important points are being made here. First, Fred challenges Dom in stating that the connectivity required for a tool like Google Earth might not be available. The uncertainty of which tools are available in the scenario (cf. Fragment 4) should not be misread as resulting from a lacking definition of the rules of the training scenario. The point made by Fred stresses that this uncertainty is realistic in that the availability of certain resources cannot be assumed in real operations. Second, Eric, by questioning how up-to-date Google Earth is, he also makes explicit its status as a non-primary source of information. This is made evident by suggesting the confirmatory recce as a primary source.

This fragment exhibits a persistent matter for disaster responders: *uncertain, unverified secondary information must often be used to plan an operation to obtain primary information*. During our back brief, the CO responded to the issues raised by this fragment in the following way:

```
Fred: The mapping issue is kind of one of the main rea-
  sons we exist ((talk omitted)) it doesn't really matter
  what Google Earth says, it doesn't really matter what
  Falcon View says, it doesn't really matter what the lo-
  cal person says we get the intelligence from. It's
  actually all bollocks until we've gone out and looked
  at it and confirmed it. This goes to the provenance as-
  pect. ((talk omitted)) no matter how good Falcon View
  or Google is, it's wrong when the disaster's here, be-
  cause it's now secondary data, it's no longer primary.
```

The CO here is describing the *organisation of uncertainty* in disaster settings, i.e., how they go about designating categorisations of primary and secondary. Categorisations are made in ways that are sensitive to the practicalities of the (real or prospective disaster) situation, meaning that use of resources like Google Earth, Falcon View or paper mapping comes to require a novel visual sensibility.

PRINCIPLES FOR SYSTEMS IN UNCERTAIN SETTINGS

We have examined key practices employed by RG members during the training exercise, particularly focusing on the co-construction of the CRIP ('Commonly Recognised Information Picture'). The bird table is the site at which the CRIP is co-constructed and updated by assembling and making use of a complementing set of physical and digital resources. Yet the CRIP is *not* just a collection of documents, it is a socially shared object. The CRIP also includes collective team members' experience, skills, practices, and understandings. The bird table is used to make elements of the CRIP visible to all. As such the CRIP acts as a 'boundary object' in the classic sense [34], offering a common point of reference for responders and their collaborators, yet *retaining* conflicting and unresolved perspectives (i.e., not just 'interpretative flexibility').

The bird table itself is developed through methods of 'filtering' and 'indexing', where in-depth work procedures are reduced and transcribed to bird-table-compatible annotations (such as a suitable landing strip, cf. Fragment 2; and tracking, cf. Fragment 3). While there is a sense in which the bird table only partially surfaces *particular aspects of* the CRIP, the annotations are taken as indexical—i.e., they are tied to, or 'documents of' [10]—the team's work practices (exhibitions of knowledge, competencies etc.), and are readily brought to articulation in discussion (e.g., the reservoir debate in Fragments 4 and 5).

In summary, a central feature of this work is the *management of uncertainty* inherent in the CRIP. Much of this is practically achieved by the construction of the bird table, which—as we have shown—is used to support the teams in retaining and preserving *uncertainties* across seams. This maintenance of uncertainty leads to a principle of generally avoiding premature resolution, and instead postponing non-resolution until it becomes critical to do so.

Principles for systems design

We propose four principles for systems design in uncertain settings that foreground different forms of uncertainty, based on the setting we encountered. We explain each form of uncertainty and its corresponding principle (see Table 2). We then map these to the HCI literature to illustrate their relevance beyond disaster response.

Uncertainty of environment (1). In planning deployment, there is a need to consider how the infrastructure in the destination environment might constrain equipment operation. This has implications on the logistics of what equipment to take; for example, in extreme circumstances Rescue Global may parachute with all their kit to set up Silver (cf. the CO's intent, Fragment 1). Therefore the first principle is to design technology support that is, ideally, *deployable anywhere*. In relation to RG's practice, this rules out bulky, heavy, large kit such as multi-touch surfaces in favour of portable, light-weight solutions, including energy efficient computers, and offline functionality.

Uncertainty of resources (2). The uncertainty of what local resources (e.g., satellite imagery, local maps, and population) are available poses a further challenge. In RG's case, the design needs to provide *flexible support for situation analysis.* In practice, paper maps could be augmented with projected information. A technical challenge would be how to calibrate a potential underlying digital GIS system to capture the same topographical space of the paper map, so that *geographically accurate* projections could me made. Aside from projecting maps onto special paper for digital pen interaction [23], a proof-of-concept augmenting actual paper maps appears to be lacking from the literature to date.

Uncertainty of equipment (3). Technology support for uncertain operational environments needs to adhere to the principle of *redundancy and graceful degradation.* This reflects RG's practice to have (at least) a secondary for each of their primary tools. Again, this supports projected augmentation in favour of replacement with devices—if the digital projection fails to work for whatever reason, the 'analogue' workflow (e.g., annotation of acetates) is still intact. This principle has further implications for possible solutions, from supporting a rich mixed-media environment (for redundancy), through to a modular software architecture that is robust to failure of individual components.

Uncertainty of information (4). Perhaps most significantly, any technology to support uncertain information needs to *support articulation work* [31] *and accountability* [10]. Our analysis showed that these features of the work are central to managing the uncertainties inherent in disaster situations. In practice, projected augmentation could for example visualise the Points of Note that index the sources and sinks of the information. Thus, providing provenance (where is it from?), and capture surrounding articulation work (who put this on here, and why?). This is similar to the design requirement by Bader et al. to *make interaction and communication attributable and recordable* [2].

Principle	Uncertainty	Practitioner's Questions	Example solution
1. Deployable anywhere	Environment (e.g., logistics and local infrastructure)	What do we take with us? How do we operate it?	Portable, light-weight, low power, offline functionality
2. Flexible support for situation analysis	Availability of resources	What local resources are available?	Projections on any paper maps
3. Redundancy and graceful degradation (primary/ secondary)	Equipment	What tools work, what if they fail?	Loose digital-physical coupling
4. Support articulation work and accountability	Information	What is the situation?	Visualise points of note indexing info sources and sinks

Table 2. Principles for system support in uncertain situations.

Relevance beyond Disaster Response

Dealing with uncertainty in systems design is a challenge faced by HCI researchers more broadly. For example, on reflecting on the challenges of deploying a location-based experience, Benford et al. propose five principles for managing uncertainty ('remove it, hide it, reveal it, manage it, and exploit it') [3]. The authors encounter uncertainties in the local infrastructure (GPS and Wi-Fi) and the equipment (hardware failures through physical strain); these uncertainties map to those in our setting (environment and equipment). Lending further support to the relevance of our principles beyond the disaster response domain, Gaver et al. also discuss the challenges of 'ambiguous information' by example of GPS-tracked players in a location-based game (cf. our principle dealing with uncertain information) [11]. In turn, our work also speaks to the broader debate in mobile and ubiquitous computing on 'exploiting' uncertainty (rather than hiding it) that was developed in reflection to—for instance—the 'seams' in the infrastructure [6], and ambiguity as a resource in design [11]. In contrast, we suggest that the sensitive nature of the collaborative work we observed renders the setting less appropriate for attempts to 'exploit' uncertainty as a resource. Our four principles are more closely aligned with strategies to 'manage' and 'reveal' uncertainties (rather than to 'exploit' them) [3], and elaborate them in the disaster response context.

Considering an Augmented Bird Table

By way of example, our principles suggest we should *augment, rather than replace* the bird table, and its constituting work practices. Our principles are also complementary to more general findings on how tabletop interaction is naturally organised [32], and more specific design guidelines for tabletop systems for emergency management [2], and crisis response [9].

Augmenting instead of replacing established and functioning paper-based workflows has been demonstrated in particular by the work around air traffic controllers' use of flight strips. From MacKay's early study that suggested to "turn the physical flight strip into an interface to the computer" [25], to Hurter et al.'s state-of-the-art realisation of StripTIC, that provides augmentation through projections onto physical strips, input through digital pens, and tracking of strips through computer vision [16].

Inspired by this work and to support the work practices described in our study we developed design requirements that we presented in the back brief to RG. The feedback provided by RG validated our requirements analysis and the efficacy of our design suggestions. RG members identified the desired prototype to be built: the *Augmented Bird Table* is a projection-vision system (e.g., similar to the PlayAnywhere system [43]), that adheres to our principles in that it

- requires only a camera, a projector, and a lightweight computer (such as a laptop) (Principle 1),
- uses computer vision to process annotations on physical acetates placed on any paper map (Principle 2),
- degrades gracefully to the standard work practice of annotating acetates if it fails (Principle 3),
- visualises points of notes that link to information sources and authoring team members (Principle 4).

The *Augmented Bird Table* uses an underlying GIS system to transform the input into geo-coded references, such as geo-locations, lines, and areas. This offers instant digital recording of geo-information for auditing purposes, for example to comply with QM processes, and to re-use this information in other forms, for example to communicate to third parties, and to connect to mapping applications for further processing (e.g., to compute routes, distances, travel times etc.). Also, it allows for projections of real-time locations (tracking). Connecting the GIS to a directory of RG's assets and tasks further allows to support resource allocation and synchronisation of reconnaissance tasks. Further, the 'provenance' of the sources and sinks of situational information is retained to aid articulation work, particularly around uncertainty. The feedback provided by RG helped to articulate priorities and refinement of key features for the upcoming implementation phase of our collaboration (e.g., tracking, provenance, integration with existing systems).

CONCLUSIONS

We have presented ethnographic findings from embedding for two weeks with Rescue Global, a disaster response organisation. Our observations of a training operation reveal how the CRIP ('Commonly Recognised Information Picture') is co-constructed as a shared social object by drawing on a variety of digital and physical resources, and rendering the results to the bird table. The bird table becomes the focal point for members to read progress, align their own contributions, and co-orient to teammates' contributions, as well as a 'boundary object' resource to negotiate how to proceed. Our fieldwork revealed uncertainty as a particular challenge that cuts across different aspects of the situation encountered in responding to a disaster. We identified four forms of uncertainties: uncertainty in the environment (e.g., the local infrastructure), resources (whether and what is available), equipment (whether it is operational), and information (whether it is accurate).

In response, we suggested four principles for designing systems for uncertain settings such as disaster response that take into account the four forms of uncertainty we identified. We exemplified how these might be implemented by way of the *Augmented Bird Table* that we are developing in future work with Rescue Global.

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