Distributed Sensemaking: A Case Study of Military Analysis

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ABSTRACT

Sensemaking frequently involves the use of representations ‘in the world’ embodied within representational artefacts. However, theories of sensemaking tend not to engage with this issue in depth. Such an understanding, we propose, is important for supporting artefact design. This article develops a perspective on *distributed sensemaking* by taking as the unit of analysis an assembly of people and/or artefacts, potentially distributed physically, socially and over time rather than the mind of an individual sensemaker. Through an observational study of military analysts we explore how a sensemaking task can be understood in terms of the distribution of task-relevant representations across internal and external representations. We conclude that in sensemaking, as with many cognitive activities, the design and interactional properties of external representational media has a profound effect on the properties of the combined distributed sensemaking system.

KEYWORDS

Sensemaking; externalized/embedded cognition; military; distributed cognition; distributed sensemaking.

INTRODUCTION

Sensemaking has been described as a process of comprehension (Klein et al., 2007), and of finding meaning from information (Weick, 1995). Representation is central to sensemaking. In sensemaking we build ‘pictures’ of aspect of the world based on data that we receive about it. These ‘pictures’ constitute our understanding. A number of theoretical accounts of sensemaking have been proposed including the data-frame model (Klein et al., 2007); Weick’s analysis of sensemaking in organisations (Weick, 1995), Pirolli and Card’s analysis of sensemaking by intelligence analysts (Pirolli and Card, 2005), Russell et al.’s Learning Loop Complex model (Russell et al., 1993) and Dervin’s Sense-making Methodology (1983). For some models (Klein et al., 2007), the focus is on processes that surround representations ‘in the head’, in the form of beliefs, or mental models. However, sensemaking frequently involves the use of representations ‘in the world’ embodied within representational artefacts of various types. As a tenet of the distributed cognition (DC) approach, Hutchins (1995a) argued that cognitive processes are best understood when we see them as distributed across socio-technical work-systems. DC argues that a complete explanatory account is not possible without considering how it is distributed across materials, time and people.

External representations may take many forms including lists, maps, charts, pictures or reference information. They may be embodied within different kinds of media with different interactive affordances. In the same way that the representation of a problem impacts how we go about solving that problem, representations in the world are thought to change sensemaking in some way. Evidence for this expectation is implicit in the extensive research into representational methods and interactive tools for supporting sensemaking tasks. However, current theories of sensemaking tend to not engage with understanding the role of external representational artefacts in depth, seldom exploring how and why they affect sensemaking processes and outcomes. With this in mind, we consider a sensemaking task which involves the use of external representational artefacts, analysing the task in a way which attends to how these artefacts support, mediate and enhance cognition during selected task elements. The task we consider forms part of a military intelligence analysis training exercise. Strongly influenced by DC our interest is to contribute to a better understanding of sensemaking as *distributed sensemaking*, with a particular interest in how external representations support reasoning during sensemaking.

In the next section we give some background on sensemaking and distributed cognition. In section 3, we present the case-study and in section 4 we then describe the case study design. In section 5 we report findings with a focus on how external artefacts affected cognition, and in section 6 we consider the implications of the findings.

BACKGROUND

Sensemaking

Sensemaking concerns the ways in which we use information to construct interpretations of the world around us. Different theories of sensemaking have drawn attention to different aspect of this process and considered it in different contexts. For example, Weick (1995) was concerned with the forces that act on sensemaking within organisational settings in which individual and social sensemaking are inextricably linked. Dervin (1983) has been concerned with how sensemaking relates to information seeking and information needs, Russell et al (1993) described how representational schema change to accommodate ill-fitting information and Pirolli and Card (2005) described a sensemaking process model based on a task analysis of intelligence analysts.

The data-frame model (Klein et al., 2007) is helpful from the perspective of offering a fairly detailed account of cognitive processes involved in sensemaking. The data-frame model refers to two kinds of entity, data and frame, which interact dynamically during sensemaking. Data are aspects of the world that a sensemaker experiences as they interact with it. A frame is a representation, which stands as an account of that situation. For example, a frame might contain a doctor's beliefs about a patient's medical condition, a pilot's understanding of his current location and heading, or a warship captain's beliefs about the objectives (and potential threat) of an approaching aircraft. In this sense, a frame acts as both interpretation and explanation of data.

The data-frame model presents sensemaking as a process of framing and re-framing in the light of new data. As the sensemaker encounters a situation, key cues or anchors support a plausible frame as an interpretation of the situation. Active exploration guided by the frame is then used to elaborate or challenge it. By extending further than the observed data, a frame offers an economy on the data required for understanding, but also sets up expectations for further data that might be available. Hence a frame can direct information search and in doing so reveal further data to the sensemaker that modifies or maintains the frame. An activated frame acts as an information filter, not only determining what information is subsequently sought, and which information is identified as relevant, but also affecting what aspects of a situation will subsequently be noticed.

The particular frame that is activated may depend on a number of factors including available cues, workload, motivation, and the sensemaker's repertoire of frames. People have different frame repertoires based on experience or training. Differences in these repertoires may explain differences between expert and novice approaches to problems. A frame creates expectations and violations can come as a surprise, bringing a frame into question and provoking a re-assessment of understanding, triggering the sensemaking process. However, a frame can be maintained in the light of conflicting data, including in the case of confirmation bias. From a representational perspective, we regard sensemaking as a process which demands coherence between different levels of representation of a given domain or area. Something 'makes sense' when what we see it as consistent with general beliefs we hold about that situation or situations like it. Finally, the different processes stimulated by the different requirements for sensemaking (i.e. elaborating a frame, questioning a frame, and reframing) also provide different support requirements and potentially different representation requirements.

Distributed Cognition

Hutchins argued the need for cognitive science to be broadened to include entire cognitive environments of which the individual is a part (Rogers, 2012). Compared with a more traditional view of cognition, distributed cognition extends the unit of analysis to encompass the ways in which cognitive processes transcend boundaries of the individual, taking into account an interplay between people, internal and external representations, and the use of artefacts which are said to form part of a wider 'cognitive system' (Hutchins, 1995a; Rogers, 2012). It argues that an explanatory account of cognition which fails to include such factors is incomplete. Hutchins and colleagues (Hollan, 2000) propose that cognition can be distributed in a number of ways, describing the distributed cognition approach through three 'tenets'. These are: *socially distributed cognition*: which describes cognitive tasks as being distributed across individuals acting together; *embodied cognition*: describing the distribution of cognitive tasks across internal and external resources and representations; *culture and cognition*: which describes cognitive processes as being shaped by cultural practices and ecologies.

Hutchins' approach has been applied in the analysis of a number of cognitive systems in situated settings, including ship navigation (Hutchins, 1995a), aircraft cockpits (Hutchins, 1995b; Hutchins and Klausen, 1996), air traffic control (Halverson, 1995) and emergency medical dispatch (Furniss and Blandford, 2006). A notable example is *How a Cockpit Remembers Its Speeds* (1995) in which Hutchins takes a socio-technical system—namely an airline cockpit—as the unit of analysis. He argued that the cockpit of a commercial aircraft performs cognitive tasks; computing and remembering airspeeds and wing configurations in preparation for an approach to landing. Hutchins conducted ethnographic observations of aircrews (pilot and co-pilot) piloting civil aircraft. His analysis presents the idea that memory in the system is made up of not just individual pilot's memories, but that much of the computation and processing required for flying a commercial airliner is carried out externally, where the pilots themselves are components of a larger cognitive system. Hutchins theorised about human ability to design and manipulate the environments in order to cognitive tasks. One such example from the cockpit is the speedbug. Speedbugs are indicators that can be manually positioned on the airspeed indicator. Pilots position the speedbugs according to standard operating procedures demanding specific speeds at specific times during approach and landing. When descending, pilots use speedbugs as indicators of desired airspeeds at various points and as a means of cross-checking to ensure the aircraft is configured correctly.

A key conclusion made by studies in distributed cognition is an account of the interdependencies drawn between actors and artefacts in their working environments. A distributed cognition analysis provides a multi-level accounts of the elements that make up a distributed cognitive system (Rogers, 2012). Interpreted through a cognitive-ethnographic lens (Hutchins, 1995a, pg.371), studies describe how abstract information structures (Wright, Fields and Harrison, 2000) are propagated and translated through representational states, and the different media and resources that are used. Essentially, cognitive ethnography is a descriptive enterprise which aims for descriptions of the cognitive task world (Hutchins, pg.371). A distributed cognition account explains how people in naturalistic settings appropriate external cognitive resources, given their particular properties and affordances, in the service of strategies to implement useful computation. In the next section we explore this in the context of sensemaking, taking as our example a study of military communications intelligence analysis.

CASE STUDY

We observed a group of ex-military personnel conducting an intelligence analysis training exercise. The exercise, which featured a simulated military landing in the UK, was designed for training roles within a signals intelligence cell. We show the structure of such a cell in figure 1. Interceptors (left) are radio operators in the field who discern radio broadcasts and interpret information from these and send it to the Direction Finder. The Direction Finder (DF) uses information from multiple Interceptors to triangulate locations of units in the field and to compile reports (Tactical Top-off report or TTO) to send to the Analyst. The TTO includes the location information as well as the radio frequencies used, details of call signs and excerpts from the communications. The Analyst uses these reports to build a situation picture and provide periodic summary assessment reports to a Supervisor. Priorities for monitoring and requests for information can be communicated upstream.

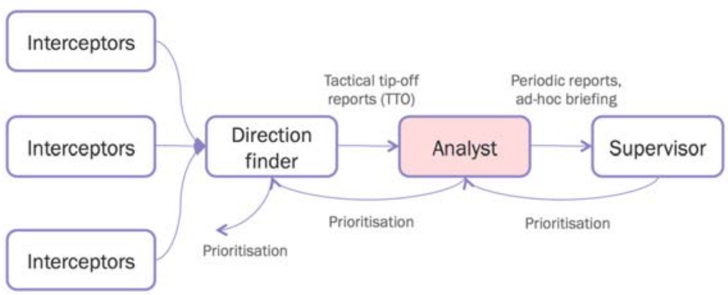

Figure 1. The analyst's role in the context of other roles within an intelligence 'cell'. For the purposes of this study we focussed on the analyst position.

Within this cell, our interest was in the analyst role. For the purposes of the study, two military trainers who designed the study simulated the role of combined interceptors/direction finder and supervisor. The analyst in each run of the scenario was an experienced in the role but unfamiliar with the exercise. The analysts used four displays in a two-by-two formation (see Figure 2). Software used by the analysts included the EW Training & Mission Support Tool (EWMST)[1] (top left screen) which enabled the geo-spatial mapping of assets in the field and the assignment of properties such as radio frequency or call signs. They also used IBM i2 Analyst's Notebook (top right screen) to create a network graph depicting command structure relationships. They used Microsoft Word to view TTO reports (bottom left screen) and created intelligence reports (bottom right screen) to send to the Supervisor. They also used instant messaging software to communicate and exchange files with the DF and Supervisor.

The analysts were also given a set of printed materials known as 'working aids'. These included the 'Radio Equipment' table, detailing information about radio types in use; the 'Radio Procedures-Callsigns' table describing call sign procedures, equipment lists, maps, and the Order of Battle (ORBAT) for the adversary force. An ORBAT describes the known structure of an army including information about command structures and hierarchies, divisions, units and formations, personnel and equipment.

For the exercise, the Analyst, DF and Supervisor were co-located (this may not occur in the field). Two runs of the scenario were observed with different participants in the Analyst position. A video camera was used to record the Analyst's workstation from an over-shoulder perspective (as in Figure 2) and recordings were made of the analyst's four screens with screen-capture software. Another camera recorded a wider view of the room. A log was created of instant message communications between DF and Analyst and between Supervisor and Analyst. Audio recordings were made of conversations and added to the video footage. The analysts were stopped by the researcher about every 15 minutes and asked to give an account of the current situation and their activities, which was also recorded. At the end of the first run, a debrief interview was conducted with the Analyst, and at the end of the second a debrief interview was conducted with the Supervisor. This final debrief outlined the normative process that Analysts were expected to follow with the information and tools provided.

[1] EWMST is proprietary software developed by MASS Consultants Ltd (UK).

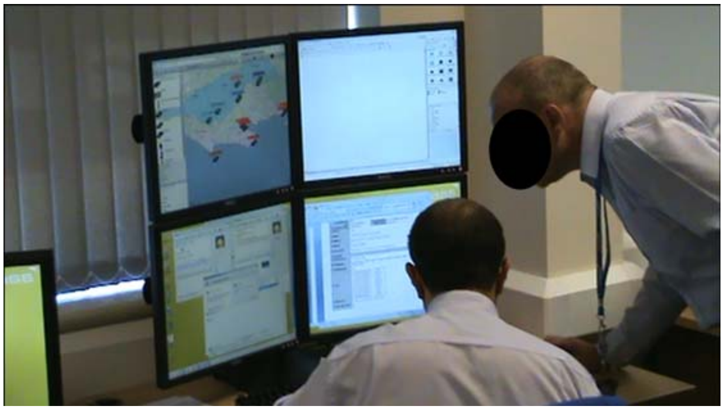

Figure 2. The Analyst's work station - shows the Analyst (sitting) and the Supervisor (standing).

The training exercise was devised and run by MASS Consultants Ltd.

Audio, video and screen recordings of the exercise were transcribed as written narratives with the support of the data collected in instant message logs. This preserved continuity and avoided fragmentation of the data allowing us to interpret the flow of information over time, and the translation of information through various resources and representations used by the Analyst. We also treated the briefing from the Supervisor in the same way, creating a narrative of the 'ideal' process analysts would take.

OBSERVATION FINDINGS

The Analyst's job was to combine information from TTO reports with background information held in tables and charts and to draw inferences about the adversary force to contribute to a 'situation picture'. Each TTO provided information about a set of intercepted communications at a given frequency. Communications at a given frequency would correspond to a sub-network within the opposing force. Each sub-network consisted of a command node and a number of subordinate nodes, although from the communications it was not necessarily obvious which was which.

When a TTO arrived, the Analyst would usually begin by plotting the communicating entities on the map (top left, Figure 2). They did this by invoking entity icons in the software and for each one inputting latitude and longitude information. With entities positioned on the map, the analyst would then use other information in the TTO to draw further inferences. This began with considering the level of command of the communication, that is, working out at the level that the entities occupied within a command structure. The Analysts had a number of tables on paper to help with this. A 'Radio Equipment' table linked known enemy radio types to operating frequency ranges, modes, and the level of command at which they were used (see this table in Figure 3).

In an early example in the scenario, a TTO reported a network communicating at 3.55MHz FM. Using the table, the Analyst reviewed the operating frequency range of each radio type to see whether it included 3.55MHz FM. This was done by visually scanning each row in turn, assessing whether or not the target frequency fell within the stated range (e.g. does 3.55MHz fall within "1.25 - 4.5 MHz"?). The table was printed on paper and the Analysts would consider the table row-by-row and used a pen to strike through those rows (i.e. radios) where the intercepted frequency fell outside the stated range. These were radios which could be eliminated from the set of hypotheses. Where the frequency fell within stated range, it was left unmarked. In the case of the 3.55MHz transmissions, this eliminated 12 of the 14 possible radio types, leaving two. The two remainding possibilities were P-404, which would imply Regiment-to-Battalion communication, and P-434, which would imply Division-to-Regiment communication.

To narrow the possibilities further, the Analysts were able to consider the 'Radio Procedures-Callsign' table (Figure 4). This linked five forms of callsign (2-letter, 3-figures) to level of command. In the example, the TTO indicated six call signs opearting on the sub-network in question, each with two letters. Again, the analysts struck out rows that the call sign form excluded. In the example, they were able to eliminate all but the '2-letters' entry which corresponded to 'regiment and below'.

Radio Designation	Frequency Range	Mode(s)	Level of Command	Role	Remarks
P-404	1.25 - 4.5 MHz	FM / AM	REGT > BN	HF CNR	
P-407	28 - 50 MHz	FM / CW	BN > COY	VHF CNR	
P-411	20 - 48 MHz	FM	REGT > BN	VHF CNR	Command Vehicles, Listening Stations & Ground Launch / Radar stations
P-423	20 - 52 MHz	FM	REGT > BN	VHF CNR	Mainly used in Tanks and Armoured Vehicles
P-426	50 - 54 MHz	FM	BN > COY	VHF CNR	Manpack
P-429	1 - 16 MHz	AM / SSB / CW	BN > COY	HF CNR	
P-430	1.5 - 13.5 MHz	SSB	REGT > BN	HF CNR	
P-434	1 - 30 MHz	AM	DIV > REGT	HF CNR	
P-443	2 - 28 MHz	AM / SSB / CW	DIV > REGT	HF CNR	
P-445	52 - 62 MHz	FM	DIV > REGT	VHF CNR	
P-503	48 - 51 MHz	FM	Various	Radio Relay / Rebroascast	Seen at all levels of command
P-707	52 - 58 MHz	FM	Various	Radio Relay / Rebroascast	Seen at all levels of command
P-709	100 - 150 MHz	AM	ARMY > DIV > REGT	UHF G2A / CNR	Used for Ground to Air (G2A) comms and for Army - Div links

Figure 3. Radio Equipment table showing radio designations, frequency ranges, level of command and other information

Type of Callsign	Example	Level/type of use	Remarks
4-Symbols	A12B	Army > Division	Used for Army to Division single channel links. Once communications have been established it is not unusual for operators to drop the callsign prefix (first letter).
2-Letters	SW	Regiment & below	Seen on most CNR networks.
3-Figures	245	Regiment & below	Used predominantly on Air Defence and Missile units.
Word + 2-Figures	MONKEY-17	Battalion > Coy (or equivalent)	Mostly seen on Recce / Chemical Recce / Special Forces and EW networks. Once communications have been established it is not unusual for operators to drop the callsign prefix (word) and just use 2-Figures.
Word	TORNADO	Division > Regiment (or equivalent)	Only seen on Divisional networks. Similar types of names are often grouped together and used for units with similar roles.

Figure 4: Radio Procedures-Callsign table connecting callsign format to organisational usage

The Analysts could now combine the results of both tables using Boolean conjunction. The first table gave *(Regiment-to-Battalion) OR (Division-to-Regiment);* the second gave *regiment and below*. Given a hierarchy of Army > Division > Regiment > Battalion > Company, the Boolean operation (performed mentally) can be described as *((Regiment-to-Battalion) OR (Division-to-Regiment)) AND (Regiment and below)*. This gave *Regiment-to-Battalion*.

Having established the level of command, the Analysts could use this information as a foothold, rather like a climbers piton, to find out other information, reviewing the TTO for content that might help to determine the type of regiment. One of the intercepted communications used an apparent codeword as if referring to an item of equipment (e.g. 'x are ready'). Finding the codeword in an equipment table showed that it was an artillery piece. From this they could infer that the communication was between Regiment to Battalion within an artillery regiment. This was reinforced when they considered other message extracts including terms like 'FP', which could mean 'firing point' and FO which could mean 'forward observer'.

Using the regiment type, another piton, the analysts were then able to then associate call signs with specific military units. This was done using an ORBAT which shows the elements within an army in term of hierarchical command structure. Finding an artillery regiment which has a battalion with the artillery piece, the analysts were able to associate it with the call sign which discussed it. They were then able to make informed conclusions and a process of elimination to determine which battalions corresponded with each of the call signs.

DISCUSSION

The case study is an example of sensemaking in action. Information about the world comes to the Analyst and provides cues making inferences that result in a frame or 'situation picture'. Cognition here is mediated by external representational artefacts and it would be difficult to explain the outcomes without reference to them.

In the study, external representations played some contrasting roles given the information that was encoded within them. We find it helpful to consider there roles in terms of elements of a functional argumentation structure. In particular we can relate them to three elements in Toulmin's model of argumentation (Toulmin, 1958). In Toulmin's model one such element is *data* or *grounds* The data or grounds are facts on which an argument or inference is built. Data in our study was encoded within the TTO reports. It also appeared as outcomes of a prior inferences. The outcome or conclusion of an inference was what Toumin called the *claim*. We see this in conclusions such as level of command. The third element from Toulmin's model we use is the idea of a *warrant*. A warrant is a rule-like proposition which provides the basis for inferences from data to claim

– effectively legitimising the inference. It is in virtue of the warrant that the inference is possible, or ratherreasonable. In our scenario, the role of warrant was played by the tables and the ORBAT. These represented generalised background information which supported inferences. Warrent information has an instrumental role as the means through which a sensemaker could find meaning from the data.

We show the three roles in Table 1, and list the information/artefacts which play those roles in the study.

Table 1. Cues (left), enabled information to be inferred (right) given mediating representations (middle).

Data	Warrant representation	Claim
Frequency	Radio Equipment table	Level of command
Call sign	Radio Procedures – Call signs table	
Type of encryption	ROM Encryption Systems Table	
Level of command, code words, call signs and message extracts	ORBAT	Unit identity
	Background knowledge	Action

Of particular interest in this study was the way in which analysts used warrant representations. In many sensemaking activities, warrant information is 'invisible' and in the head of the sensemaker. This knowledge, which may be associative or rule-like, or based on some sort of model comes with experience. In our study the associations or rules were externalised and visible in the form of tables and charts. This is not to say that the analyst may not come to remember this information - in fact our experience suggested that often they do, but knowledge represented in the tables and charts allowed the analysts to go beyond a potentially incomplete knowledge, and to work systematically within the limits of this knoweldge, optimising the set of possibilities considered.

The tables represent associations between data and possible interpretations of those data. Importantly though, by supporting elimination and annotation, the tables allowed the analysts to maintain an external representation of a working set of plausible hypotheses. In a study of medical diagnostic reasoning, Feltovich et al. (1984) refers to such a set as a *logical competitor set* (LCS). Josephson and Josephson (1996) use the term *differential*. In the current study, the LCSs were printed on pieces of paper and the analysts had pens. The performance of each inference was a question of inspecting a range statement (e.g. 1.25-4.5 MHz) and testing whether a frequency fitted within each range. Recording the results of each inference was a question of whether or not to strike through a row with a pen. The task then became a question of visually assessing the remaining rows. The tables therefore served as an external representation of judgements to be made about frequency, as a memory of which possibilities or hypotheses had been eliminated, and which were still being considered.

The properties and affordances of representational artefacts are central to the part that they play in a distributed cognitive system. A distinction made by Hutchins that is illuminating in this study is between the descriptive level of computational function and the level of representation and implementation. At the computational level, the analysis system (of analysts and representational artefacts) makes inferences, constructs LCSs, and so on, along the way to producing the situation picture. At the level of representation and implementation, the system is one that manipulates, transforms, and combines representational media (for instance, by using information in a TTO to strike out items in the Radio Equipment table, to narrow down the set of possible organisational units involved in a communication).

The link with Josephson and Josephson's (1996) account of abduction is significant. Inferences in sensemaking have been noted as often being abductive (Klein et al., 2007). Elimination through the LCS, as we observed, corresponds with reasoning to the best possible explanation, or abduction, at least on Josephson and Josephson's (1996) treatment. And yet at a lower level of description the process of elimination supported by material artefacts was deductive. Each elimination step was an application of *modus tolens* and it is this which gives the approach its strength, since a valid deduction is truth preseving. Hence the Analysts avoided jumping to conclusions; they elminated what they could reliably eliminate and considered what was left. They 'knew what something wasn't before they knew what it was'. So long as the reported frequency (data) was correct and the information in the table (warrant) was also correct and exhaustive, the conclusion (claim) of the elimination was guaranteed. Further, this deductive computation became possible by virtue of the material properties and affordances of the artefacts themselves.

Our interpretation of the Analyst's strategies is that, given the computation they wanted to perform, and the material properties and affordances of the representational artefacts, they constructed a strategy through which the computation was implemented. Further, we assume that it is through 'seeing' the strategy as a possibility, as having an expected user-cost and as providing an outcome which is expected to be helpful to the overall sensemaking enterprise, the computation that it implements becomes a possibility and something worth doing. By changing the nature of the artefact, how it represents its information and how the user can interact with it, we might change any of the former properties and hence the properties of the associated computation.

In this paper we have explored how the performance of a military analysis task can be analysed as being an instance of Distributed Sensemaking. A central commitment of this analytic perspective is, following Hutchins' cognitive ethnographic approach, to take a distributed system of people and artefacts as an appropriate unit of analysis, rather than the actions or mental process of an individual analyst. This system involves internal and external representational state and media. The analysis focuses on the properties and affordances of representational artefacts, such as the ease with which paper tables can be annotated in the computational process of making inferences. In this view, distributed sensemaking is seen as a process of transforming and propagating representational state in order to make interpretations, consider 'competitor sets', alternative hypotheses or 'frames', and develop a rich and reliable situation picture.

The subsequent phase of this research has been to explore the implications of sensemaking design requirements for technologies that are designed with the intention of supporting sensemaking and analysis activities. Essentially, we are using the Distributed Sensemaking analysis to inform the design of technologies which effectively re-engineer the cognitive process, improving factors such as cognitive load and speed. The sensemaking design requirements combine the ethnographic approach described here, along with adapted cognitive task analysis methods to inform a Designing for Sensemaking (DfSM) method.

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