Situation Awareness as Distributed Cognition

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ABSTRACT

In this paper we argue that the predominant models of Situation Awareness (SA) are inadequate for the study of systems operated by teams. The reason for this is that these models are based on mentalistic assumptions focusing almost exclusively on individuals. We suggest that, to study the control of dynamic systems, it is necessary to shift the unit of analysis from the individual to the whole cognitive system comprising a team of people as well as the artefacts which they use. Thus, our vantage point is the theoretical framework of distributed cognition. Through two field studies we try to demonstrate how team situation awareness is actively constructed via the communicative practices which the team uses in its work.

Keywords

Situation Awareness, Distributed Cognition, Dynamic systems, Co-operation, Co-ordination.

INTRODUCTION

Situation Awareness (SA) is an intermediate state in the decision-making process of dynamic systems where one should be able to comprehend the situation in order to make an appropriate decision for future development. One of the more general and widely agreed upon definitions of SA is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995:36). Endsley is treating the phenomenon in quite traditional cognitive science models with the general focus on attention, perception and memory. SA becomes another box in the individual's mental machinery, "an individual act bounded by the physical facts of the brain and body" (Resnick, 1991:1). The strong mentalistic and individualistic bias in cognitive psychology combined with the primarily focus on the aviation domain (Vidulich, Dominguez, Vogel & McMillan, 1994; Carretta & Lee, 1995; Wang & Houck, 1995) has lead SA studies to focus on first person experienced perceptions. These constraints in theory and practice have reduced SA to be an individual mental skill or ability (McMillan, Bushman & Judge, 1995). In the pursuit of a method to unfold this skill or ability, sense-making negotiation and interactive processes as well as technological support are forgotten. However, in most situations involving dynamic decision making and control of dynamic systems the task is undertaken by a team. Domains such as surgery, air traffic and underground line control, process industry and military command all constitute examples of dynamic systems where teamwork is essential and where non-individual-centred approach is also necessary.

DISTRIBUTED COGNITION

The predominant individualistic and mentalistic perspectives take the individual's mental capacity as the starting point. Failure to retrieve information from the long-term memory, or misunderstanding the meaning of representations and the limited capacity of the working memory, are all taken to be the innermost explanation of human error. The human actor becomes a passive recipient of information or an information-processing unit which encodes and retrieves information from memory. However, by adopting the distributed cognition approach (Hutchins, 1990, 1995, 1996) we instead shift our focus from the individual actor to "how information is represented and how the representations are transformed and propagated through the system" (Hutchins, 1995:287). According to this view the people as well as the artefacts they use are regarded as constituting a cognitive system, where cognition is the product constructed as a consequence of co-ordinated work

between the units of the system. Cognition thus is an dynamic and emergent construct, rather than a static feature and mental architecture. Furthermore, cognition is not formed in a social vacuum. Many practices and notions have been formed by earlier practitioners over time, only to become incorporated in the operators' situated actions. Using a distributed cognition approach the task is to describe how cognition is distributed and co-ordinated. However, adopting this framework does not mean, as some antagonists assume, that the individual is abandoned but rather that the individuals' roles are confined to "providing the internal structures that are required to get the external structures into co-ordination with another" (Hutchins, 1995:131).
Distributed cognition requires the analyst to analyse interaction rather than mental properties. Whether we focus on people interacting with an artefact or interacting team members we must understand that cognition is constructed and formed as consequence of the resources and information provided by agents combined with the information and resources the individuals themselves provide. This means that much of the cognitive content and co-ordinated negotiations will not be bound to one single person but will rather tend to be distributed between individuals.

Thus the deficiencies of the traditional approach are overcomeby a distributed approach. This approach takes the *system* as the basic unit of analysis instead of the individual. It focus on practices of sense-making instead of mental constraints, and it allows the analysis to see co-operating individuals as a cognitive system.

SITUATION AWARENESS AS DISTRIBUTED COGNITION

As already mentioned most co-ordination centres of dynamic systems consist of a team where each individual has some specific responsibility and roles (see Heath & Luff, 1992; Hutchins, 1990). However, the currently predominant models of SA has little to say about the co-ordinated effort of teams. Some efforts have been made to shape a theory of Team SA (Salas, Prince, Baker & Shrestha, 1995; Wellens, 1993) but no agreed upon theory has so far been formulated.

Most co-ordination centres do not only consist of teamswith access to many technological devices, they also tend to be detached from the actual environment they are supposed to control. This means that the operators at co-ordination centres are often connected to the dynamic system via information obtained indirectly. Thus they have no first-hand experience of the actual situation, and consequently no direct feedback. Therefore, they rely on other persons or on artefacts, protocols and descriptions of the situation, and have to actively construct an understanding from the information presented to them. In addition, the different team members have different domain knowledge, as well as different information resources, which must be combined and co-ordinated. Furthermore, time-constraints often apply which call for parallel task execution. The situations confronted are seldom alike and therefore cannot be dealt with by routine methods or by a static prescriptive organisation. Consequently, teamwork calls for negotiation between team members, and we would overlook an essential feature of the team's situation awareness if we attributed the sense-making process to a single individual. The distributed cognition approach, which takes the interactional and negotiational practices as its primarily unit of analysis, avoids reducing team practices to individual or social attributes.

Wellens (1993:272) defined group SA as "the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future", and Salas, Prince, Baker, Shrestha (1995:131) defined team SA as "at least in part the shared understanding of a situation among team members at one point in time". Although we do not fully disagree with these definitions we would like to stipulate a definition that puts more emphasis on the interpretative and distributed nature of team SA; "The active construction of a model of a situation partly shared and partly distributed between two or more agents, from which one can anticipate important future states in the near future." This accomplishment emerges in a context where artefacts and information technology partly structure the possibility to share and distribute information.

CENTRES OF CO-ORDINATION: TWO FIELD STUDIES

The empirical data through which we will here revisit SA are drastically different from the ones obtained from the aviation domain. The operators in these settings rarely have visual contact with the scene where a problem may have arisen but which they nontheless have to deal with. In the following we will describe how two teams co-ordinate their assessment of the situation through distribution of tasks and interpretations.

Emergency Co-ordination Centre

Sweden has 20 emergency co-ordination centres (ECC) in which several operators work around the clock receiving emergency phone calls from the public. When a case is identified as being an emergency the operators send out the appropriate resources such as medical help, the fire brigade, the police etc. The emergency centre thus distributes the execution of tasks and is responsible for the co-ordination of the organizations involved until a command unit arrives at the incident and takes over responsibility for co-ordination.

We will here look at a example of how the ECC operators take care of a very complex situation. It is a Friday evening around 8 p.m. and at this time the unit is loaded with calls as, is usual on Fridays. A person calls in and describes, for almost 30 seconds, to operator 1 that she is depressed and has been feeling very ill. Feeling bad or being depressed is seldom an acute state, and in addition it is an awkward way of introducing oneself to an emergency centre if one expects to receive quick help. Therefore it is no surprise that the stressed operator responds in a rather reserved but polite way[1].

Time	Operator 1	**Operator 2**
0.00	SOS-Central (inaudible)	[Works with another case]
	And how do you feel now?	
0.28	Ω	
	Have you done it yourself	[Hangs up]
0.32	Why?	
	Ω	
0.38	[*Call for Assistance]*	*[Looks around]*
0.47	Ω	
0.49	It is still in your arm now, is it?	[Takes assistance]
0.54	Ω	Ω
	Huh, it a big knife then?	
0.58	Ω	
1.00	Let it stay there till the ambulance comes	*[1]Let it stay there do not move anything!*
1.02	Ω	Ω

We can see how operator 1 is polite and answers the 30-sec.-long statement of being depressed by asking how the caller is feeling now. The caller replies by saying that she driven a knife in her arm. Operator 1 maintains his composure while he responds. Usually, when something like this happens the operator who has taken the call recites aloud significant words uttered by the caller, thereby making it possible for a second operator who is not busy, to pay attention and become aware of the existing problem. At the same time operator 2 is looking around in the room by mere routine, not paying any attention to the particular call or to operator 1. He does not seem to get the impression that the call is urgent. Shortly thereafter operator 1 calls for assistance and operator 2 directly 'taps in' to the call and is then able to hear the caller through his headset. Note that does not, when he taps in to the telephone call operator 2 know anything about he actual emergency since he lacks the information from the caller. The first operators' suspicion can be explained by the primacy effect where what comes first still affects the interpretation of later information. However, when hearing about the knife in the arm but having not heard the beginning of the conversation, operator 2 is not suspicious. Instantly he reacts to the latest information by telling operator 1 to tell the caller not to move the knife. This illustrates how the team SA develops as different operators with different domain knowledge and information contextualisations get involved.

In the subsequent episode the operators become startled by what the caller tells them; the knife has been in the arm for about 20 hours! Could this really be true? Operator 2 asks about the described situation to operator 1, and the latter in turn nods vigorously. Then operator 2 undertakes the process of deciding which ambulance to send. He therefore involves operator 3, who is responsible for the information of the location of the ambulances.

Time	**Operator 1**	**Operator 2**	**Operator 3**
1.11	And you did this last night, did (..)		
	Ω		
1.16	*[Nods]*	*Uhuh, [towards 1] Is the knife still there?*	
1.17	Ω	Ω	
	[Writes the phone number into the	ooh, damn it	
1.28	database]	Ω	
		[3]What do you think [3] What ambulance do	
1.30	Yes	*we have in town?*	
	Ω	*[3]Should we take ambulance 4?*	
1.31	[repeats phone number]	Ω	
	Ω	Ω	
1.34			*[2]Yeah, we could, yes uhu You..*
1.35	Yes, and what is your name then?	*[3]Do you have contact? No.*	
1.37	Ω	Ω	
1.40			[*2]No, [town], u'know No,*
1.41	Door... Are you able to open the door?	*Uhhuh*	*take 941 then*

Operator 1 asks the caller for her 'phone number and name in order to match those with the information on a 'phone number database. This matching procedure is yet another way of establishing the

identity and credibility of the caller. By using the database to do this we can say that the assessment of the situation is distributed between the operator and the information contained in the database he accesses. While operator 2 is asking operator 3 about the status of the ambulances the former is at the same time listening via the headset to operator 1 who is asking the caller further questions. Operator 2 must send an ambulance instantly, but must first also co-ordinate with operator 3 about the availability of ambulances in the area.

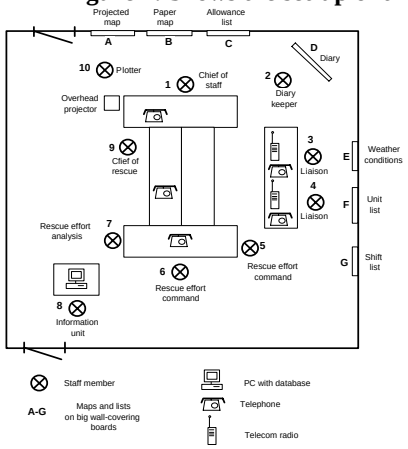
However, matters get more complicated! It turns out that the caller, who is almost unconscious, has locked the door of her apartment from within. Without access to spare keys, the emergency management operators will have to arrange to breakdown the door to the apartment. Again it is operator 2 who lets operator 1 understand what must be done. Operator 1 in his turn notifies the caller that the door has to be forced to enable medical help to reach her. The awareness and anticipation of the situation is once again distributed between the operators and must be co-ordinated by communicative acts. Operator 2 then calls the ambulance which has been suggested by operator 3. While the fire brigade was sent to force the door so that the paramedics could enter, the police were also notified of the action taken by the fire brigade. Once again this notification procedure was distributed and conducted in parallel; operator 1 called the fire brigade while operator 2 simultaneously called the police. The cognitive tasks of co-ordinating the many items of information - already known information, the information given by the caller, the information provided by the other operators, the information accessed through the database, the allocation of resources, the aspects of the personal status, the information order etc. - are all indeed emergent, cognitive co-operative accomplishments.

Team situation awareness through public representations

The second field study, which we will present here, is based on a staff command training session at the Swedish Rescue Services Agency. The purpose of the training was to practice staff command strategies and techniques. The participants in the training session were all highly skilled professionals, meaning that many of them had several decades of experience from their particular domains. They represented professions such as coast guard, fire chief, police inspectors, local and provincial authority rescue services etc. During the training session the team members were constantly given information from a special 'simulator group'. This group consisted of people from the National Rescue Services Board, all experienced in training rescue control. The simulator group closely monitored the activity of the team and fed it with the appropriate information according to a prepared scenario. Thus the members of the simulator group simulated the fire brigade, police, ambulance etc. at the scene of the accident.

The scenario which the rescue command group was faced with during this particular session was a leaking valve on a train wagon filled with 45 tons of LPG (liquefied petroleum, commonly referred to as bottled gas). The increasing temperature at the leaking valve in combination with the high pressure created a major explosion threat. Considering the fact that the rest of the train consisted of similar wagons also filled with LPG, the team was faced with the potentiality of a gigantic catastrophic explosion. The set-up of the rescue command room is illustrated in Fig. 1. As can be seen from figure 1 the rescue command room contained a lot of different artefacts all of which were essential to the work of the staff, though in quite different ways. However, we would like to maintain that all of these artefacts are not simple filters of reality but rather active elements in the construction of the operators' model of what is happening at the scene of the accident. In other words, these artefacts are essential in the process where the team members construct a model of the system they control and are responsible for.

Figure 1: Shows the set-up of the room



In the upper right corner in the layout of the control room we find a diary (artefact D). The diary consists of a big paper pad which the diary keeper (nr 2) constantly updates. The role of the diary is twofold. First, the information coming to the staff from the units at the scene of the accident is taken down. Second, all the decisions taken by the rescue command team are recorded. The diary is updated on a temporal basis so that the exact time is written in front of each incoming piece of information or decision taken. Ten minutes after the staff has come together the delayed chief of rescue (nr 9) arrives to the staff. While the chief of rescue is taking his position, the chief of staff (nr 1) starts to brief him on the situation. But just as the chief of staff starts doing that, he pauses, turns round and takes a long

look at the diary (artefact D). While he is still looking at the diary the chief of staff begins the briefing. Eventually, the chief of staff takes his eyes from the diary and faces the chief of rescue and continues the briefing.

Analyzing this situation from a distributed cognition point of view, we can say that the chief of staff, *together* with the diary briefs the chief of rescue. The chief of staff does not, and cannot, keep in mind all the events that have occurred at the scene of the accident, as well as the decisions taken by the rescue staff in the preceding ten minutes. There is simply too much information. Due to the time pressure the diary denotes only a brief sentence of every event. This means that the diary as such contains only the necessary but not the sufficient information on the decisions and events. When looking at the diary, the chief of staff has to actively interpret the information displayed on it and construct a history of the situation so far. Thus, in this particular instance the diary contributes to the team's *retrospective situation awareness*. It helps the team to understand how they got to where they are at the moment.

Moving over to artefact F, on the right hand side wall, we find a list including all the units which the rescue command team disposes and which are sent to the scene of the accident. Responsible for updating this list are the two liaison operators (nr 3) and (nr 4). When they receive information about the units they add it to the list. By doing that the liaison operators also make the information accessible to all their team members, so that everyone in the room can easily obtain the represented information on the unit list by looking at it. For example when the rescue effort analyst (nr 7) needs to know how many police units and which ones are commissioned to the area around the accident site he does not have to ask the liaison operators who have quite a hectic time. Rather he takes a look at the unit list and thereby retrieves the information he needs. Through its public representations, meaning that they are immediately available and accessible to all members, the unit list becomes one of several artefacts which contribute to the formation of the team's *contemporary situation awareness*. Of course each team member could have had his own list containing the information about the unit status which is relevant only to his own sub domain. But then each individual list would have looked different since the staff members would have had to find a way of constantly updating each others' lists in order to obtain a shared understanding.

Finally we will briefly examine artefact A, at the top of the figure, which is a line-art map of the accident area. This map is projected by an overhead projector on a whiteboard. The map is relational and only indicates the position of the train with the leaking gas wagon, a nearby plant as well as urban areas which could be threatened by the gas cloud that would follow from an explosion. Furthermore, the line-art map contains specific representations only for that particular context, and is thus stripped of other sorts of information such as a street grid of the residential areas around the accident scene. The plotter (nr 10) can draw movements of units, weather conditions or any other features that he wishes to display on the whiteboard where the map is projected. The very fact that map A is projected on the whiteboard makes it possible write on the projection and thereby add or remove information in an easy, flexible and quick way.

About an hour into the work of the rescue command team we find a 'bubble' drawn on the line-art map. This bubble represents the spread of a gas cloud, which would follow an explosion under the current weather conditions. Thereby, the current information on this map indicates the most possible future state of the accident scene within the time scale which the team has chosen to work with. We have to remember that part of the work of rescue management control is to try to predict the future situation and to suggest necessary actions in order to limit any deterioration of the emergency and prevent further damage from taking place. Therefore the team need to work on a different time scale than the ones 'out there'. Quite a few times during the team's work we find several team members in front of this future status map engaged in serious discussions accompanied by a lot of pointing on different spots on the map. In other words the line-art map helps the team members constitute a *prospective situation awareness*.

The three artefacts which we have used as examples in our analysis indicate that they do indeed play an active role in the formation of the teams situation awareness. Their role in the propagation of information around the rescue command cognitive system can be described as acting as *cognitive catalyzers*. That is because the artefacts contain the necessary but not the sufficient information. The team members must in addition interpret the information and make sense of it. Therefore we can also say that the artefacts must be considered as equally important parts in the process of building up a model of the situation 'out there'.

CONCLUSION

It is interesting to notice that in an environment where the process as well as the information is truly distributed no single team member or artefact can be said to constitute an information hub in its on. All team members and artefacts should be considered as integral parts of the rescue command cognitive system. This also means that there can exist a collective state of mind which is not represented in any single locus (Weick & Roberts, 1993). We also want to point out that it is as possible to identify the temporal aspects of team situation awareness when

adopting the distributed cognition as it is when considering individual SA (Endsley, 1995).

In the illustrations which we have provided it was evident that the teams' model of what was going on in the system was clearly distributed. In the first example this is done through extensive discourse and a delicate practice by which operators anticipate each other and the future situation. In the second example we examined the role played by the publicly represented information displayed on the artefacts which they used. We found that the artefacts are integral parts of whole cognitive system and the way it works. In both our field studies we found that discourse as well as artefacts have to be actively and collectively interpreted by the team members in order to make sense and so contribute to the construction of shared SA. We suggest that the future development of the concept of SA must take into account the distributed nature of cognition. Otherwise it will fail to provide essential insights into how people control dynamic systems.

Footnote

[1]The transcription is a simplified version and only includes talk between the operators that is connected to this incident. Some of the facts of the incident have been changed to make it anonymous. Text in italics signifies co-ordination and communication between the operators. The omega sign (Ω) is used to signify the caller's remarks (not transcribed) which reach the operator though the headset. [1-3] means that the talk is directed to operator 1-3.

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