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Situation Awareness in Emergency Medical Dispatch

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Abstract

Situation Awareness, and how systems can be designed to support it appropriately, have been a focus of study in dynamic, safety critical contexts such as aviation. The work reported here extends the study of situation awareness into the domain of Emergency Medical Dispatch (EMD). The study was conducted in one of the largest ambulance services in the world. In this study, we encountered development and exploitation of situation awareness, particularly among the more senior EMD operators called allocators. In this paper we describe the notion of a 'mental picture' as an outcome of situation awareness, how an awareness of the situation is developed and maintained, the cues allocators attend to, and the difficulties they face in doing so. One of the key characteristics of ambulance control is that relatively routine behaviour is periodically interspersed with incidents that demand much higher levels of attention, but that the routine work must still be completed; operators exhibit contrasting levels of situation awareness for the different kinds of incidents. Our findings on situation awareness are related to those of others, particularly Endsley and Wickens. The observations and interviews enable us to propose high-level requirements for systems to support appropriate situation awareness, to enable EMD staff to complete their work effectively.

Keywords: situation awareness; EMD; systems design; ambulance control; HCI.

Introduction

Maintaining awareness of the situation is often key to success, particularly in dynamic situations that demand rapid decision making. Ambulance control – or Emergency Medical Dispatch, to give it its formal title – is one such work domain. Understanding how situation awareness is developed and maintained can provide guidance for the design of systems that support this crucial

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perceptual and cognitive activity that sets the stage for decision making. Situation Awareness (SA) is a phenomenon originally described by military aviators to refer to being vigilant in observing and drawing inferences from developments around them. We extend the study of SA into the domain of Emergency Medical Dispatch (EMD).

EMD is defined as the "reception and management of requests for emergency medical assistance in an emergency medical services (EMS) system" (Clawson & Dernocoeur, 1998). It involves two broad aspects of work: call-taking, where calls for emergency medical assistance are received and prioritized; and controlling, where the most appropriate ambulance is dispatched to the emergency and ambulance resources are optimized in their areas of operations.

Background

As will emerge in the discussion of findings from this study, many different lines of research contribute to our understanding of EMD work. The focus of this paper is on the development and maintenance of Situation Awareness; however, it also relates to work on other forms of awareness and naturalistic decision making. We include a brief review of these topics. Other aspects of the work, such as its social nature (relying heavily on team working and coordination of actions), are also essential to its success, but are outside the scope of this paper.

Situation Awareness

Situation awareness has been defined by Endsley (1995) as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and projection of their status in the near future". Most past work on situation awareness has taken place in dynamic environments such as aviation (Jentsch, Barnett, Bowers & Salas, 1999; Wickens, 2000) and air traffic control (Endsley & Smolensky, 1998; Gronlund, Ohrt & Dougherty, 1998).

From studies such as these, Endsley proposes a 3-level model of SA to explain her observations about SA. The three levels are perception, comprehension and projection of the situation (Endsley, 1995). Level 1 SA (perception) refers to perceiving information of, and therefore being aware about, the status, attributes and dynamics of various entities in an environment. Level 2 (comprehension) refers to the integration and interpretation of that information to explain what is happening in that situation. Level 3 (projection) expresses the prediction of a future state should the situation continue. The outcomes from this continuous assessment – what's happening here and now? And what is likely to happen next? – are used to plan and to decide on the next course of action.

From Endsley's model, we can see how deficiencies in developing and maintaining this awareness can lead to major problems. For example, a momentary loss of SA by a combat pilot arising from the failure to detect or perceive changes in the position of a hostile aircraft could allow the hostile aircraft to manoeuvre into a superior tactical position. The failure to perceive the change might lead to an incorrect understanding of the situation and hence prediction of where the hostile aircraft might be. This leads to poor or erroneous decisions such as placing one's own aircraft at a disadvantageous position. Having good SA is crucial in decision making. Jentsch, Barnett, Bowers, & Salas (1999) show how the loss of SA can lead to errors in assessments that could result in major accidents – in their case, in aviation.

Wickens (2000) suggests that pilots need to have good SA in three related areas:

(i) awareness of the external environment, or hazard awareness,
(ii) systems awareness, and
(iii) task awareness.

Awareness of factors in the external environment, such as hazards, the weather, terrain and other aircraft in the surrounding space, allows the pilot to steer the aircraft in a safe and expeditious manner. System awareness refers to the state of the processes and the computers that control the processes; this awareness is crucial for responding to unexpected events. Pilots also have several tasks that they, their crews or automated agents are responsible for performing; they need to be aware of the state of completion of these coordinated activities.

A number of studies into SA have explored how technology can be used to improve SA in dynamic and information intense environments. For instance in military aviation, efforts have examined the design and evaluation of novel displays to help pilots more efficiently develop and maintain SA (van Breda & Veltman, 1998; Williams, 2000). In commercial aviation, studies have investigated the effect of automation on aircrew communication and co-ordination (Field & Harris, 1998). Zhang *et al*. (2002) has shown that integrated 3D displays can improve situation awareness of anaesthetists.

However, while technology plays a significant role in helping operators develop and maintain SA, it is also important to understand how various aspects of the nature of the cognitive work in each domain act to influence SA. In Air Traffic Control, Grondlund *et al* (1998) found that air traffic controllers developed better SA when they recognised the importance of aircraft under their control, as they maintained explicit awareness of these aircraft, rather than providing better flight data alone. Jones and Endsley (2000) found that the lack of expectedness of information can result in the misinterpretation of a situation. These are known as representation errors which are, in Endsley's terms, a Level 2 SA deficiency that can lead to poor decisions.

This brief review of the SA literature suggests that being able to perceive critical cues about the external domain, the systems and the tasks, and then to comprehend and project a future state of the situation, are important to making appropriate decisions. To build systems that can help provide information updates in a manner compatible with the demands of the EMD task, it is important to have a better understanding of the nature of the cognitive work performed by ambulance controllers.

Peripheral awareness and selective attention

It is widely recognised that people maintain awareness of many aspects of their environment, through both selective attention to some features of it and peripheral awareness of others. Awareness is achieved through many channels simultaneously, most notably visual, auditory and touch. One of the criticisms of traditional computer displays (e.g. MacIntyre *et al*, 2001) is that the limited screen 'real estate' constrains possibilities for maintaining background awareness of other tasks and of other events happening in the broader context within which activity is set. Although not widely discussed as such, these tasks and other events comprise part of the 'situation' that is of concern in work on situation awareness; for example, Wickens (2000) discusses the design of displays that would allow a pilot to focus attention on the current task at hand while also maintaining background (or 'situation') awareness of other events in the environment that might lead to critical situations demanding immediate attention.

People are generally aware of much information that is not the current focus of their attention. This peripheral awareness of background information enables people to rapidly switch attention to new matter if it becomes salient to them. In the case of pilots, as discussed by Wickens (2000), this may be when some anomaly is detected between the expected and actual situation. A more widely familiar phenomenon is the 'cocktail party effect', whereby in a busy room, with many conversations going on in parallel, an individual can maintain focused attention on one conversation, with peripheral awareness of others, but can shift attention to a different one if something salient, like their name, is heard. Arons (1992) reviews the features of conversation that facilitate the maintenance of focused attention on one coherent conversational stream, including the spatial quality of sound and the differences in people's voices. As discussed below, this ability to maintain awareness of background events and 'tune in' to salient information is an important element of allocators' skill that they call 'control ears'.

Naturalistic Decision Making

EMD, like aviation and many of the other domains in which SA has been investigated, has a large naturalistic decision making (NDM) element. The characteristics of naturalistic decision making include that work is typically performed under time pressure, that there are high stakes (e.g. lives at risk), decisions have to be made with inadequate information and team co-ordination is essential (Klein, 1998) – all features of EMD. However, EMD also differs from these other domains, in being reliant on discrete information updates rather than the continuous changes that typify dynamic environments.

NDM has been explained as "the way people use their experience to make decisions in field settings." (Zsambok, 1997). Field settings refer to real-time situations that are dynamic, time constrained, uncertain, and where the consequences of wrong decisions are significant to both the individual and the organisation (Klein, 1998). The study of NDM involves probing experienced people working in these natural settings about how they assess the situations they face, determine the problems they need to address, then plan, make choices, and take actions.

Such studies have improved our understanding of how decisions are made in these complex, dynamic and real-time environments. While the decision-making processes of EMD operators are not the focus of this paper, they are relevant to understanding the role of SA in their work.

Studies of EMD

Although there have been a number of studies in the domain of emergency ambulance control, covering issues in workload modelling (Henderson & Mason, 1999; Zhu, McKnew, & Lee, 1992), software design and reliability of real-time, life-critical systems (Finkelstein & Dowell, 1996), software usability of dispatch systems (McCarthy, Wright, Healey, Dearden, & Harrison, 1997), and decision making processes (Hajdukiewicz, Burns, Vicente, & Eggleston, 1999; Wong, Sallis, & O'Hare, 1998), none have previously focused on the role and maintenance of situation awareness in this context.

The next section describes the methodology adopted in this study to characterise the cognitive work of ambulance controllers.

Methodology

The field study reported in this paper involved a number of different methods of investigation, selected to be appropriate to the domain of study, and to provide complementary information to yield a broad understanding of the nature of the work of EMD operators.

(i) Initial interviews with senior and key management staff within the organization, including initial visits to the control room and reading corporate documentation on procedures and practices, identified formal current practice and issues that managers perceived as being important. This phase also helped us to understand the formal relationships in the control centre.

(ii) Existing performance data (which is routinely gathered for statistical reporting purposes by all ambulance services) was analysed to establish some of the key factors that influence EMD performance.

(iii) In-situ observations and Contextual Inquiry interviews (Beyer & Holtzblatt, 1998) were conducted to gather data focusing on routine operations.

(iv) Critical Decision Method (CDM) interviews (Hoffman, Crandall & Shadbolt, 1998) were conducted to find out more about how staff perform during major incidents.

The initial findings from the study were then presented at a meeting with the control centre managers, supervisors and the EMD operators themselves, to verify the results and to correct any misinterpretation of the data. Some of this work, focusing on method and conceptual models, has been reported elsewhere (Blandford, Wong, Connell, & Green, 2002; Wong & Blandford, 2001a, 2001b). For the purposes of this paper, we briefly describe the observations, Contextual Inquiry interviews and CDM data collection, and the subsequent data analysis. Because the study was not set up specifically to investigate SA – that emerged as a key theme of the data as it was analysed – the questions were not structured specifically around SA themes.

Observations and Contextual Inquiry interviews

The purpose of observations and interviews was to gain a familiarity with the tasks, organisation and work processes, and to establish how routine work is performed and how various information artefacts are handled and managed.

Observations focused on high-level aspects of the work. For example, this included noting the layout of the control room, the positions of shared information resources (such as an electronic notice board that displayed the number of calls waiting or in progress) and the visible mechanisms whereby staff co-ordinated their activities. Such observations helped provide the context for understanding the details of staff activities and aspects of their work, such as the situation awareness that is the focus of this paper.

Observations were supplemented by Contextual Inquiry interviews. Contextual Inquiry is an approach promoted by Beyer and Holtzblatt (1998) that helps members of a design team gain a deep understanding of how users currently work, and hence identify valid requirements on the design of new systems. The key features of the approach are that the design representative carefully observes users, and then enhances their understanding by asking probing questions about the work – for example, why users do particular activities, whether others performing the same role have the same procedures, how they record particular information and what happens to that information when it gets out of the local environment. These questions are asked in the context of the ongoing work. For Beyer and Holtzblatt, Contextual Inquiry is an early stage of Contextual Design, in which findings are used as a basis for constructing various models of the current system, leading on to system redesign; in the work reported here, only the interview technique was used.

This basic approach was taken for studying routine operations in the ambulance control centre. Staff representing the various roles were observed and asked about their work. Eighteen members of staff (4 allocators, 5 call-takers, 3 dispatchers, 4 radio operators and staff working on two specialist desks) were observed and interviewed, each for 60-90 minutes. Questions covered their perceptions of the current technology, their understanding of the external environment and the nature of their decision making. Since the work is time- and safety-critical, and workload is generally high, much of the time was simply spent observing the individual and their team, rather than inquiring; the pattern of observation and interview was dictated by the pattern of emergency calls: as soon as a call was received, discussion ceased, and was only resumed when the staff member had completed their outstanding tasks. In practice, because any discussion was frequently interrupted, it was not possible to probe any issues deeply within the control room setting.

All observations were audio recorded and hand-written notes were taken to describe non-verbal activities; a few observations were also video recorded. All audio data was transcribed for analysis. Data was systematically analysed qualitatively. For example, one analysis entailed identifying all concepts the different user groups were working with and constructing a domain ontology (Blandford *et al*, 2002); for understanding situation awareness, all transcript extracts that related (positively or negatively) to SA were extracted and further analysed. Most of these extracts came from the observations of the five most experienced staff. Positive examples of SA were considered to be any statements that indicated awareness of the situation at any of Endsley's (1995) three levels – i.e. the situations of components in the environment, understanding the significance of the situation, and planning on the basis of that understanding. Negative examples were considered to be cases where the member of staff said something that indicated that they had lost situation awareness. These data extracts were analysed qualitatively to identify the key themes that emerged from the data regarding how these members of staff developed and maintained situation awareness, and how they used that SA. For the main analysis, no pre-existing framework (such as that of Endsley (1995) or Wickens (2000)) was used, so that the main themes identified were those that emerged from the data. A subsequent re-analysis related our findings to those of other researchers in SA.

As noted above, the observations and contextual inquiry interviews gave insights into routine operations. During the time spent in the control room, we observed one incident that forced the responsible team of operators to start dealing with it as a major incident; this was an aircraft in difficulty on its approach into one of the region's airports, which turned out to be a false alarm as it landed safely; we also missed another incident (a train crash, in which nine people were injured) by a day; this was considered small enough that it was dealt with in the control room, rather than separately. To probe behaviours during (infrequent) major incidents, a CDM study was also conducted.

The Critical Decision Method Study

The CDM is a cognitive task analysis method that involves a retrospective protocol analysis of critical incidents (Hoffman, Crandall, & Shadbolt, 1998; Klein, Calderwood, & Macgregor, 1989). The first stage involved selecting a memorable incident that the participant had personally experienced. We then asked the interviewee to reflect upon the incident to develop a time line for it. A participative technique using sticky PostIt™ papers and pencil was used to create the time line (Wong, Sallis, & O'Hare, 1997). This approach was found to be useful in engaging the interviewee and it seemed to encourage them to articulate their thoughts during the interview. Once the decision time line had been created, we used it as a framework to probe their memories about what they did, attended to, considered, actions taken, and their reasons for those actions, at each decision point. This process is referred to as 'progressive deepening'.

One criticism of all retrospective techniques is the accuracy of recall. The CDM interview uses a number of triangulation techniques to raise the reliability of the recalled information. For instance, the re-construction of the incident by creating the decision time line allows the interviewee to visualise the incident and make corrections to their recall of activity sequences. Interviewees are not just asked to report on what they did, but instead to describe what a person sitting next to them would have seen them do or hear them say at each decision point; this allows the interviewee to identify the more tangible aspects of their work, which then helps them recall the more cognitive and less overt aspects of work such as the cues attended to and the options considered. Another set of questions explores the demands they faced, such as what kinds of mistakes a less experienced person would make in the same situation. Such questions provide insights into the level of expertise and the challenges presented by the incident. Collectively, these techniques help the interviewee recollect and re-construct the events as accurately as possible.

A total of 13 EMD operators were interviewed, investigating 11 different major incidents. The incidents included a major train crash, a terrorist bombing, and a chemical leak at a public swimming pool. Six of the interviewees were allocators, four were radio operators who had also functioned as allocators when the allocators were on breaks or unavailable (one of whom was relatively inexperienced in the allocator role), and three were telephone dispatchers. However, only incidents from the nine more senior interviewees – the six allocators and the three most experienced radio operators – are discussed in this paper as the incidents reported by the remaining four interviewees were found to be limited in scope and lacked the detail needed for the study. Collectively, these nine interviewees represent about a quarter of the staff at the centre involved in the role of sector allocator.

The CDM focuses on data collection, leaving scope for different forms of analysis. In this study, the interviews were transcribed and analysed using the Emergent Themes Analysis (ETA) approach (Wong & Blandford, 2002). This is a concept distillation process where broad themes across the different incidents are identified; the broad themes that emerged were related to the stages of naturalistic decision making:

(i) assessment of the situation,
(ii) assessment of resources available,
(iii) planning and selecting a course of action,
(iv) controlling and coordinating the plan, and
(v) situation awareness.

Specific themes within each broad theme were then identified, and structured according to an organising framework that explicitly described: activities that the allocator did at that time; the information he or she used or attended to and the considerations made with that information; the knowledge and experience that they brought to bear on the decision at that time; and the difficulties faced and likely mistakes one might make. A written narrative was then developed to describe how these allocators worked during the critical incidents. As with the Contextual Inquiry data, for this paper the focus was on situation awareness (theme (v)), and emergent themes were identified before relating the findings to previous work on SA.

The next three sections first present an overview of the organisation and the work, and then present and discuss the findings from this study.

Emergency Medical Dispatch at an Ambulance Control Centre

The ambulance control centre at which this field study was conducted is considered one of the busiest in the world. It receives at least 3200 emergency calls a day (compared to 'hundreds' in other control centres we have visited, or that described by Martin *et al* (1997)). It is responsible for controlling about 400 emergency ambulances, 14 smaller fast response units and a helicopter, deployed over 70 ambulance stations distributed over a densely populated urban area of about 1,600 square km.

Organisation Structure

Control centre operations are organised in two parts, a call-taking group and a dispatch group, each occupying a separate area within a very large room. There are about 20 EMD operators working on call-taking at a time. The call-takers are usually less experienced than their colleagues in the ambulance control group.

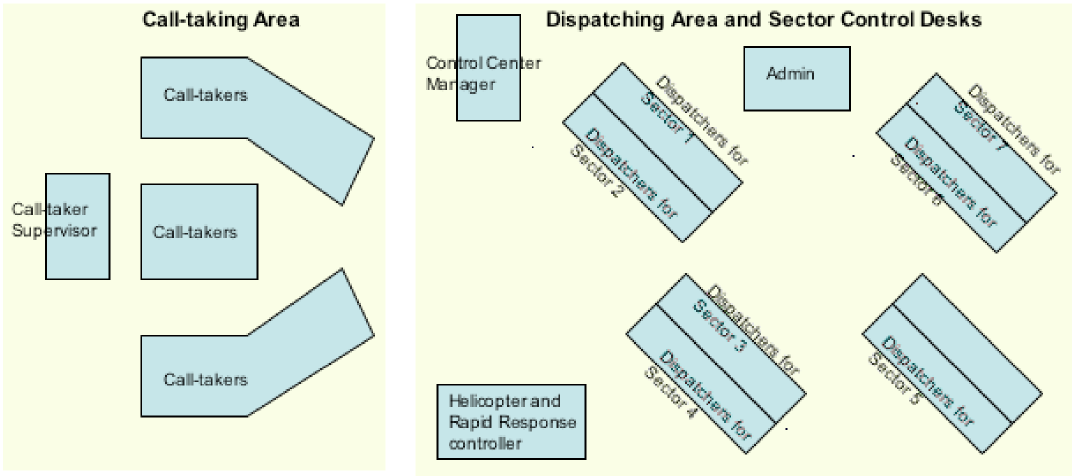

Figure 1. Layout of the Control Centre.

The control of ambulances is carried out in the dispatch area of the control centre. This area is divided into seven sector control desks, mirroring the operational sectors in the city, plus specialist desks that deal with matters such as managing the Helicopter Emergency Medical Service or co-ordinating vehicle maintenance (see Figure 1). Each sector desk is half of a large physical desk (adjacent sectors occupy the two sides of the physical desk); each has space for four members of staff and their working equipment. Each sector control desk is led by a sector controller, who generally also takes the role of allocator, deciding which ambulance is assigned to a job. During the busy hours of the day, each allocator may be controlling up to 45 ambulances, which may be dispatched to between 20 and 30 incidents simultaneously. The allocator is assisted by a radio operator, who sits on their right and communicates with ambulances travelling to or from a job. The radio operator constantly communicates with ambulances on the road, giving them dispatch instructions, updating them with developments and receiving reports from them. The allocator is also assisted by one or two telephone dispatchers, located on their left, who are responsible for communicating with ambulance crews that are still at the stations, and with other emergency agencies such as the police or fire service control centres (see Figure 2).

Figure 2. Sector desk; from left to right, Telephone Dispatcher, Allocator, allocation box, and Radio Dispatcher.

Staff typically progress through the roles, learning the responsibilities of the next position partly through training and partly on the job. In particular, when an allocator takes a tea-break, their position is usually taken by their radio operator, and that position is taken by a telephone dispatcher, so that each spends short periods of time performing in a more senior role. See Table 1 for a summary of job experience in each role. While most staff spend most of their time in one role, and stay on the same sector desk indefinitely (so that they get to know the geography of that area well), a few senior staff are peripatetic, taking any role in the control room in response to immediate needs.

Call-takers	Telephone Dispatchers	Radio Operators	Allocators
Less than 9-12 months	9-18 months	2-4 years	5-8 years

Table 1. Summary of Typical Job Experience by Role.

Workflow

The following description of workflow is based on our field observations and study of documented operational procedures at the control centre. It refers to practice at a particular time – late 2000; new technologies are being systematically introduced and procedures changing in order to improve performance and respond to ever-increasing demands. As far as possible, we focus on the principles of EMD operation, rather than specific details of implementation, although the two are necessarily interrelated.

When a call-taker receives a call, they record key details, such as type of emergency and address of the emergency, into the Computer-Aided Dispatch (CAD) System. A unique CAD Number is automatically assigned to each call record. The call-taker will also ask the caller a systematic set of questions to assess the medical priority of each call. These prioritization questions have been defined by the emergency medicine community and have been encapsulated in a criterion-based system called the Advanced Medical Priority Dispatch System (AMPDS). For example, a heart attack will be given a higher priority than a broken leg resulting from a fall because, although both incidents require medical care and transport to hospital, the former is immediately life-threatening whereas the latter is not.

Given the address, the CAD System automatically assigns a gazetteer (map) reference and directs the call record to the appropriate ambulance sector desk. A call summary, indexed by CAD number, is displayed on the allocator's 'overview' screen, including an indication of the medical priority of the call. The allocator can 'drill down' to see call details. In deciding how to respond to the call, the allocator has to determine whether this call is for a new incident or is a further call about an already-known incident; they also have to assess the kind of response the incident requires. For example, a cardiac arrest occurring in a busy shopping mall may require a motor-bike first responder (to deal as quickly as possible with the patient's condition), to be followed by an ambulance for patient transport. The allocator then has to assess which is the nearest appropriate resource, while also ensuring that using particular vehicles will not leave an area under-resourced.

Once the call-taker has marked a call as 'completed', the call details are printed onto a paper job ticket at the appropriate sector desk. From this point on, the dispatch system transfers from being computer-supported to being paper-based. If the assigned ambulance is at the ambulance station, the allocator hands the ticket to the telephone dispatcher to activate the ambulance or (if the ticket is not yet printed) simply tells the telephone dispatcher the CAD number and which station to send a vehicle from. If the assigned ambulance is on the road or at a hospital, the ticket or CAD number is given to the radio operator, who will communicate with the ambulance crew via the radio system. Changes to the situation are recorded by hand on the paper ticket. The status of the ambulance on the job (e.g. arrived on scene or on the way to the hospital) is recorded by writing the times at which status changes occur on the tickets. Some of this status information is indicated by the physical placement of the tickets on the desktop and in a slotted metal box, known as the allocator's box, which has one slot for each vehicle being controlled in a sector (see Figure 2). When a vehicle is out on a call, the paper ticket (or tickets) corresponding to that incident are placed in the slot. Since the allocator's box is located between the allocator and the radio operator, the tickets are available to both, and provide an overview of activity in the sector. When an ambulance crew reports that they are free after an incident, the ticket is turned round in the slot, and when they report that they have returned to the ambulance station, the ticket is removed, checked and filed. Thus, the spatial placement of physical artefacts within the workspace conveys meaning – a practice that has also be observed in other information intense, socio-technical environments such as air traffic control (MacKay, 1999). The main elements of this process are illustrated in Figure 3.

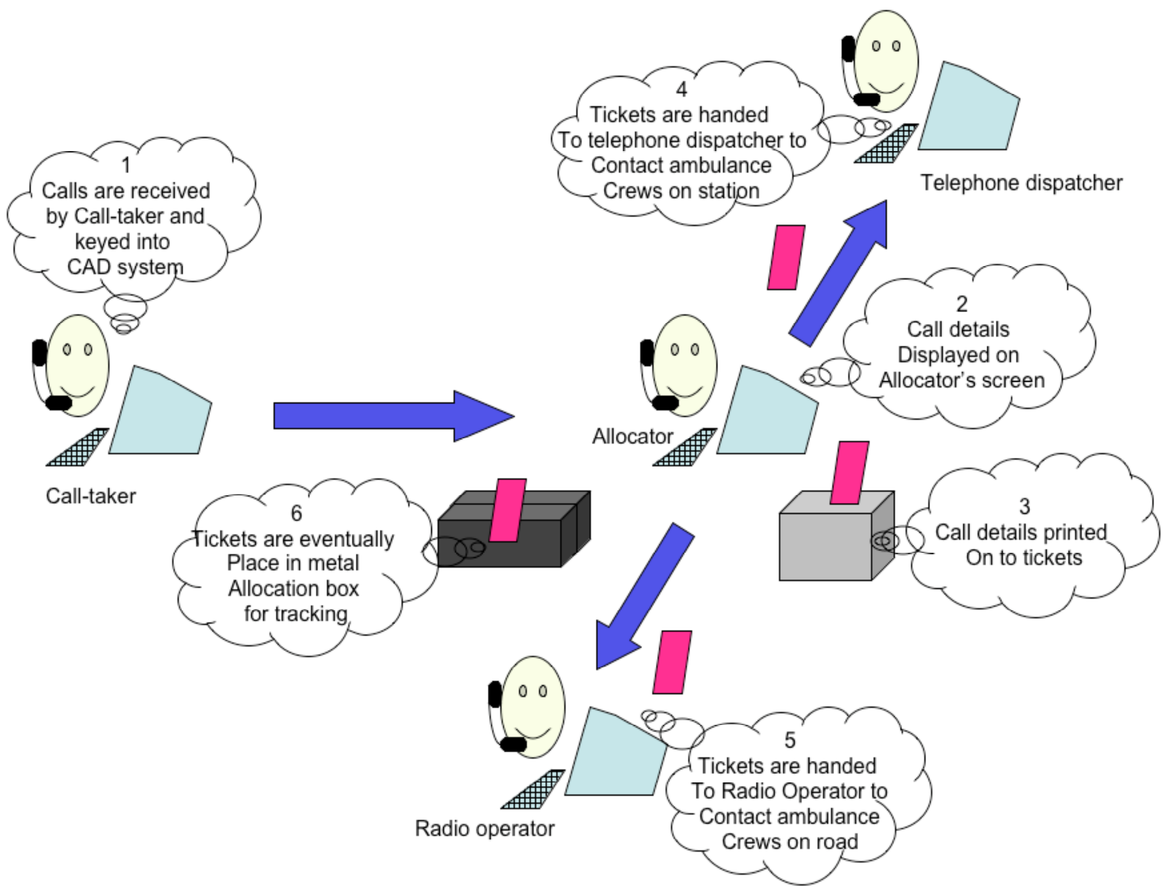

Figure 3. Schematic of call-taking and dispatch process.

Workload

As noted above, dispatch teams often have to deal with large volumes of information generated by high workloads. One question we asked was whether this large volume of information has a significant effect on the time taken by an allocator to activate an ambulance? Activation time is computed as the difference between the time when the address of the incident is entered on the system and the time when the ambulance is *en route* to the incident. 358,866 daily call records, representing the daily dispatch performance data for 116 days (or approximately a four month period), were analysed. The results showed that there were two bands of activation time performance:

(i) a ‘low’ workload band in the range of 29-91 calls per hour, with a mean ambulance activation time of 2 min 8 sec. This band occurs from after midnight till 8am, and

(ii) a ‘high’ workload band in the range of between 105-156 calls per hour, with a mean ambulance activation time of 3 min 38 sec. The high workload band starts from 8am till midnight.

The results indicate that activation times doubled from approximately 2 minutes to approximately 4 minutes from low workload periods to high workload periods. A *t-test* showed that there is a significant difference between the two sets of mean activation times ($p<0.05$). These results are illustrated in the chart in Figure 4, which shows the mean workload and the mean dispatch time per hour of the day, aggregated over the total time period studied.

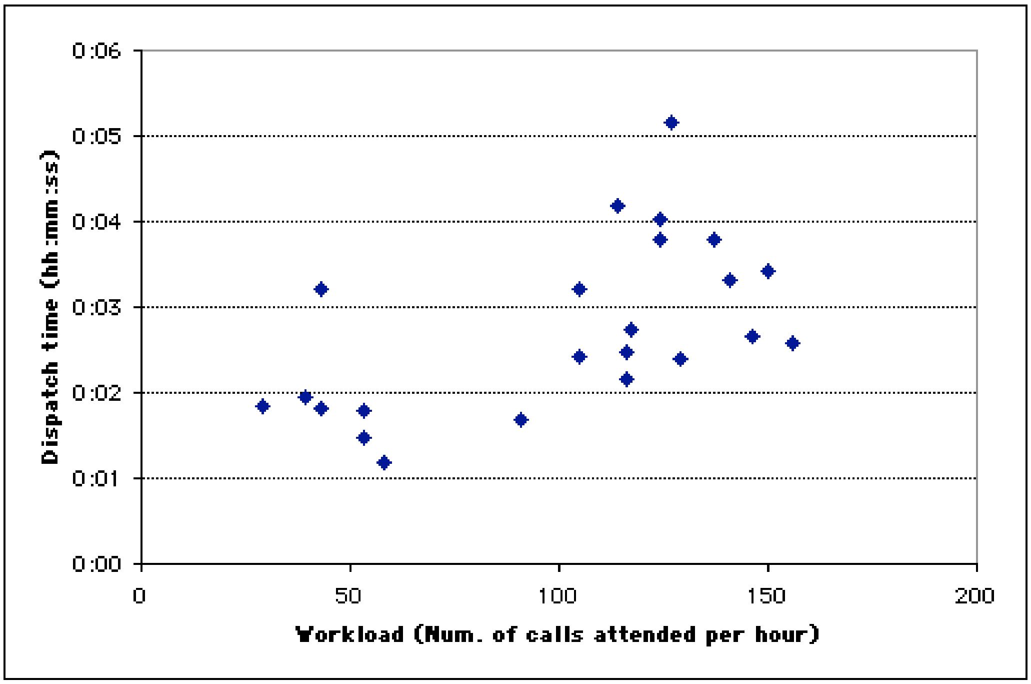

Figure 4. Activation time increases from 2 min to 4 min when workload increases from 50 to 120 calls received by the control centre per hour.

A number of other factors, many of which are interrelated, also contribute to activation time. For example, if workload has been high for a while, more ambulances will already be engaged on a job and so will not be available, meaning that allocators have to reconfigure the remaining vehicles more often, or have to wait for the most appropriate ambulance to become available. Similarly, high workload may result in more hospital admissions, which reduces the number of hospital beds available for new admissions, so ambulances have to wait at hospital and are not available. All of these factors result in higher immediate workload (more calls to process) and also higher load for dealing with each call, which overall make increased demands on the information handling capacity – cognitive and technological – of the EMD operators. Situation awareness – such that operators do not need to rapidly assimilate large quantities of new information to support each decision – is therefore likely to be particularly important under high workload conditions. Conversely, under such conditions, it is vital that operators keep abreast of information developments in the environment in order to maintain SA and make appropriate decisions. Therefore, understanding how these EMD operators develop and maintain SA in their dynamic environment should lead to the design of systems that will help them cope with the complexities of the work.

Results and Discussion

One key feature of EMD work that emerged from both the observation of routine work and the CDM interviews is that work can be classified broadly into three phases:

(i) during routine work, the allocator is dealing with a large number of vehicles and incidents; each takes relatively little of the allocator's time; the primary focus of the allocator's concern is on the deployment of their vehicles, and relatively little attention needs to be paid to any incident once the initial decision about what resources to send to it has been made.

(ii) as a major incident, or possible major incident, starts, the allocator has to divide their attention between the routine calls and this one incident. This is effectively a transition time, which is the time of highest workload for the allocator. Some possible major incidents, such as the aircraft in difficulty described above, turn out to be 'false alarms', while others escalate to be formally treated as major incidents.

(iii) once a major incident becomes established as such, and if it assessed to be large enough, it is processed separately from the routine sector work. A dispatch team is set up to deal specifically with that one incident, away from the main control room, under a separate structure called 'Gold Control'. This involves physically moving all the resources needed to manage the one incident to another nearby room.

In the discussion that follows, we present our findings regarding SA under routine operation (i) separately from those during transitions and major incidents (ii and iii), for which SA of an individual incident becomes an additional consideration. These roughly, but not exactly, correspond to findings from the contextual inquiry interviews and the CDM interviews. Extracts from transcripts are used to illustrate findings; in these, respondents are referred to as C1, C2, etc. for contextual inquiry interviewees, and D1, D2, etc. for CDM interviewees, and questions from the investigator are indicated with 'I'. The 'C' and 'D' interviewees are different individuals; extracts are drawn from both sets of transcripts to illustrate points; since CDM interviews touched on routine as well as exceptional behaviour, there is not strict demarcation between the two sets.

Situation Awareness during routine operations: keeping track of a dynamic situation

Situation awareness during routine operations is partial and selective. It also varies according to role and experience. Broadly, the level of situation awareness increases with experience and responsibility. As discussed more fully below (for critical incidents), senior EMD staff refer to situation awareness as resulting in a 'picture in the head'. In the context of control room operations, they consider the situation with the jobs presented on the CAD system. Except where otherwise indicated, the following discussion focuses on the role of allocator.

In general, allocators displayed much more awareness of the situation than call takers; however, experience was a key determinant in developing SA. For example, we observed one call taker who was a senior operator, taking any role in the control centre as needs demanded, whose way of describing incidents showed her developing a picture of the incident as she talked to the caller. For example:

C8: So she's inside and she's fallen down, but she can hear them outside, and she's saying she can't open the door. It's not like she's in there dead or anything – they know she's alive and breathing but they don't know what she's done.

I: The lady on the phone didn't quite say all that, you sort of pieced them all together?

C8: Yeah, well she said she could hear her, the lady inside had said that she couldn't get up to open the door, so she's obviously conscious and breathing and she's probably hurt herself in some way because she can't get up.

Other telephone dispatchers did not display this tendency to develop a picture of the incident. In practice, even allocators did not show much tendency to picture routine incidents, in terms of the way they described them; however, they paid enough attention to each incident to determine what resources it was likely to need. For example, talking about a 'baby born at home' (BBA) one allocator explained:

C3: Then I have to send the nearest vehicle, obviously, and I have to send a hotel crew, as well – a paramedic crew, right? I also have to notify – find out what hospital she's under, and see if they've got a community midwife, or need a midwife picking up. So if it was a BBA, birth at home, then it could consist of three ambulances all tied up on that one call.

For more unpredictable incidents, such as road traffic accidents, allocators use subtle cues in the way information is conveyed to them to estimate the resource requirements. As illustrated here, they are not always able to articulate what cues they are using:

C3: And it's funny: you sit here and you get, there's just something, just instinct, you think 'that's going to be a bad one, I'll send another ambulance'.

I: And you've no idea what

C3: No, but 99 percent of the time it works. You go there and they say send another ambulance, and we say there's one on the way for you. You know it's funny, it's just… ha ha.

One allocator showed goal-based selective attention in maintaining awareness of the locations of his vehicles, with minimal information about their whereabouts (at the time of this study, the control room did not have a mapping system that showed them vehicle locations, although one has since been introduced). In the following discussion, the vehicle had reported itself available at hospital several minutes earlier, and the allocator chose a particular moment to direct it to a (non-emergency) incident:

C3: On the radio, when they come up at hospital, [Radio Operator]'ll say "I've got one at [named hospital]". From that point, they are available, so then they're turned round the other way.

I: Yes. What brought that to your attention?

C3: They were returning from [hospital], and the call was to [region in city]

I: So you're just aware…

C3: I'm aware that they're returning and the way the vehicle is travelling back to their own station. What I didn't want to do is give them it at [hospital] because you might have a call between [hospital] and [station]

I: So you were waiting until…

C3: Until it gets back further to a certain point

I: So you're imagining exactly where they are on the route?

C3: That's right: what way they're travelling. […] it's just by judgement of knowing your areas.

Similarly, sector desk teams would loosely track how long a crew had been on a call, and start trying to contact them – whether to check on their safety or to drag them off an unauthorised break – if they had been out of contact for longer than expected. Also, we very occasionally asked operators to tell us where a particular vehicle was, and each time they could tell us correctly without consulting the allocator's box.

However, this situation awareness was far from complete. On some occasions allocators (including C3, who sometimes exhibited good awareness, as illustrated above) showed relatively little awareness of available resources – for example, asking a team member whether there was a vehicle available at a particular station. Thus, they appeared to loosely track their vehicles, but not always to make the mental step from that to knowing quite how their resources overall were deployed (e.g. whether any were available at a particular station). As well as not always tracking the overall resource distribution, allocators maintained only a partial awareness of incidents, as confirmed by C7:

C7: I can't remember every single call that everyone is on, but sometimes you get a call through, not all the time because you sometimes forget you've sent a crew, but most of the time you think 'oh that rings a bell', […] you can't remember every single address, there's just too many all day.

Overall, allocators appear to maintain whatever degree of awareness they anticipate needing to perform their work effectively; this typically includes minimal awareness of routine incidents (once they have been resourced), partial awareness of what resources are free, and selective awareness of vehicles that are on a call, loosely tracking their likely locations and using this information as necessary. This is consistent with the view of Endsley (1995, p.38), who states that "An operator's SA needs to incorporate information on that subset of the environment that is relevant to tasks and goals".

Emergency calls have to be processed immediately, so maintaining situation awareness of emergency calls entails monitoring what is coming in while dealing with the current call. In practice, most calls and other queries or interruptions can be dealt with rapidly (as a single episode of attention). Only more complex calls – tending towards those that might be classed as major incidents – demand extended periods of attention, as multiple resources are mustered and deployed. For these, the allocator has to perform regular attention shifts, to monitor the state of the rest of the sector and ensure that other emergencies are not being ignored. This was described graphically by one allocator:

D4: Well, you have to look, you just have to keep looking, scanning through if there's a different call coming in, from a different area, then you just treat it as a normal call and dispatch somebody, and you're all the time trying to keep an eye on what's building up on your own, on the other, on the um, the major incident.

In addition, paradoxically, doctors' urgent calls add to the mental workload, because they are typically *not* responded to immediately. 'Urgent' calls are an intermediate category between 'emergency' and 'patient transport', typically requiring a response within two hours, so the allocator keeps the paper tickets corresponding to these calls on the desk, occasionally flicking through them or re-ordering them as part of the process of planning how to deal with them:

> C3: See whilst these emergency calls are coming in, you still have to start thinking about these urgents because your time is now lapsing.

In summary, during routine operations, allocators' SA is selective, focusing on what they perceive as mattering for the effective performance of their duties. In particular, they maintain much higher awareness of the locations of their vehicles while on the road and of non-routine incidents than they do of routine incidents. The greater attention to details of incidents emerges for non-routine incidents – particularly for critical ones.

Situation Awareness during major incidents: a 'picture in the head'

As noted above, one of the key themes that emerged in this study was the idea of a 'picture in the head'. Just as Air Traffic Controllers have referred to the situation as a 'picture' (Endsley & Smolensky, 1998), so six of the nine sector allocators interviewed during the CDM study also used the word 'picture' to refer to the situation when discussing how they managed major incidents. They have used the word 'picture' to mean to have an understanding of what is happening in the overall situation of a particular incident, for example:

> D5: …I want to really know what's going on. So I'm just having a look to, … to get a feel of it, looking for an overall picture.

> D1: … we just try and picture everything … everything has to be a picture in your head of what's going on.

The analysis also revealed at least another two different concepts associated with the word 'picture', namely the situation at the scene:

> D6: … really, you get a mental picture don't ya … because you can just imagine a swimming pool with lots of kids walking around, ambulances, and people collapsing around.

and the situation in the vicinity of the scene in terms of a mental map of the area in one's mind:

> D8: … You get a sort of picture in your mind where the areas are, [… it's] like a sort of a little map of where all the stations are and the hospitals, and then you start, you know the running times back from hospital to the station, like in ten minutes, five minutes.

We need to understand the value of such a picture, and why allocators build this picture. Knowing what is happening around them is important to making appropriate decisions about future actions:

> D1: … to have a picture of what else they need, what more can we be doing.

This picture – a mental map of the area and how the ambulances can move around the area – is needed to help them develop and evaluate a plan,

> D7: … you gotta have roughly a picture in your head on what you're going to do, how you're going to do it...deal with it, and where you're gonna send your resources to get the best access to the patients without endangering the crews and also be able to get them out as well safely, the patients.

These aspects of the situation correspond with the areas described by Wickens (2000) – external environment, systems, and tasks – that a pilot needs constant awareness of. The outcome from understanding, and having an awareness of, the situation in these areas is the notion of a mental picture. Thus, we see strong parallels between the SA of pilots in highly dynamic situations and those of operators in the context of EMD – particularly for major incidents.

How do allocators develop and maintain their mental picture of the situation?

Allocators act as information hubs and collators of information. As information hubs, allocators function as centres of all information flowing in their sectors:

> D5: I know everything that's going on, because all the information comes through me.

Allocators get most of their direct information from within the control room, although much of that information originates from the external environment.

Allocators work with their teams to actively seek new information for known or anticipated events. They expect changes and they actively look for them. Correspondingly, the radio operators and dispatchers push any new and relevant information to the allocator, usually notifying the allocator in an unintrusive manner. For example, one radio operator explained:

> C2: Basically, I need to always keep [allocator] informed of what is going on with the vehicles, where they are and running back from, where they're available, so [allocator] gets a running sort of tally of where all the vehicles are at any particular time and vice versa.

One element of the radio operators' responsibility is to maintain awareness of the situation with regard to their vehicles; one of the techniques they apply for doing this is regularly checking the allocator's box, to make sure that everything in there is recorded correctly and reminding themselves of the current situation:

> I: Can you see the big picture in your head?
>
> C2: Yeah, try to, and that's where every five minutes or so I just go through the box checking where all the vehicles are and checking all the paperwork is up to date.

Similarly, some (though not all) telephone dispatchers try to maintain overall awareness of incoming calls by flicking through the incoming calls screen when they have free moments, and notifying their allocator of calls for their sector.

Information also arrives through other sources within the control room, such as the computer system, the wall panel (displaying statistics of the number of calls being processed and waiting), conversations on neighbouring sector desks, and through the special placement and physical handling of tickets.

Within the room, 'control ears' are used to selectively listen for key things that help maintain an awareness of what's going on around them. For example, one operator described them:

> D9: it's not like a sixth sense, it's just, they call it control ears. … you tend to learn to do, like I say, more than two things at once, or three or four or five things at once. … I think being aware what's going on around you and what's going on in the control room.

'Control ears' gather cues that impact ambulance availability. Allocators listen for …

> D9: special things … like vehicles coming out of hospitals

These cues provide them with information about the transient states of their vehicles such as likely availability. Such information, rather than just definite availabilities when the ambulances are on station, are used for planning and minimising delays between jobs.

Other cues they attend to inform them about job status. These cues include the new calls that are displayed on the computer system, the positions of the tickets in the allocator's box (indicating whether a job is completed or being queried), and unassigned tickets laid out on the desk for sorting and planning.

Allocators appear to be able to access the information flowing around the control centre with minimal effort. This is in part due to the open design of the control centre that allows for the easy exchange of visual, verbal and tactile information. Although staff within the room can communicate with each other by telephone, in practice few do this, much preferring to shout or to walk over and talk with a colleague, both of which help maintain the flow of 'control ears'-level information around the room.

While the allocators emphasise the importance of hearing as a means of maintaining background awareness of events, both within the control room and relating to events outside, touch and vision also play important roles in helping them maintain this awareness. For example, they touch and shuffle tickets that are laid on their desks as part of the process of maintaining awareness of outstanding tasks (relating to doctors' urgent calls, as discussed above), and monitor the wall panel to ensure they are alerted as early as possible to a change in the pattern of calls (which might indicate a major incident).

Although direct contact between allocators and the outside world is limited (since call-takers process all calls), there are several cues that prepare them for potential problems. These cues include duration of call, which may indicate a problem call, the call rate, which usually rises rapidly at the start of a major incident, information communicated to the control room about on-road developments, such as road and traffic conditions which could present travel problems, and crew emotional state, especially after attending traumatic cases – a crew welfare and effectiveness issue.

With these many sources of information, it can take an allocator a long time to build a good picture of the situation for a major incident, particularly because it comes in over a period of time, and is interleaved with information about other incidents. For example, D4 explained that he took two to three minutes to gather together enough relevant details, from the different emergency calls coming in from the public and an on-scene report from a fast response unit, to "… build up a picture" of the situation involving a major train crash.

Just as it can take time to develop a mental picture, so jumping into a situation mid-stream and trying to follow the developments from recorded events is often difficult. For example:

> D1: It's all up here, you know what's happening, you know what's going on, you know what's been done and its difficult for someone to jump in.

In practice, at shift change (during routine operations), staff endeavour to leave matters as clear as possible for the incoming allocator, as the incomer has little time to 'get up to speed':

> C5: On the early turn it's not too bad because it's a little bit more quieter so in the mornings you can kind of check the box to see what you've got and what you haven't got, coming in on a late turn you've just got no chance.

The outgoing allocator will brief the incoming one with minimal information:

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C3: I've left you a [station] one to [hospital]. We've had a fatal RTA to
    [vehicle crew], right.
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Difficulties in maintaining situation awareness in the control of emergency ambulances include the need to constantly collate and interpret information. Developing situation awareness to construct the mental picture is made difficult because it involves integrating pieces of information across different sources and modalities, and over time. Also, as noted above, information about an incident is often interleaved with information about other incidents. Relevant information therefore needs to be teased out from an undifferentiated stream of information, and during the transition period when staff are dealing with both a major incident and routine operations within the sector, they need to frequently switch attention between the different incidents to ensure they maintain awareness of all developments in the sector. Furthermore, allocators often have to work with second- or third-party information. The lack of direct access to the originating sources of information prevents them from interrogating and clarifying the information.

Discussion: relating findings in EMD to those in other contexts

Comparing our finding to those of Wickens (2000), we find that EMD controllers needed good SA in the same areas. They need to know what incidents have occurred and where those incidents are; this corresponds with hazards awareness, or awareness of the external environment. Systems awareness corresponds to awareness of what their ambulances are doing, where they are located, and what fellow controllers in the centre are doing (so that they can co-ordinate their efforts). Task awareness relates to both emergency calls, which should be dealt with immediately (except in a few situations such as when the incident is classified as low priority and there is a shortage of vehicles), and urgent calls, which have to be dealt with more slowly, but nevertheless in a timely way.

However, the pilot's SA, as described by Wickens, differs in some important ways from that of EMDs. The pilot's attention is generally focused on the dynamic task at hand, and the challenge of designing displays to ensure SA is that of enabling the pilot to gather background information about the broader context of working, so that he or she can become aware of hazards (whether in the environment or caused by systems failure) and deal with them in a timely way. In contrast, in EMD, the allocator's task during routine operations is to process discrete task units in a timely way – most of them as a single episode of focused attention. Because there are 'slack times' between routine calls, allocators have short intervals in which to update themselves on the broader situation, as well as using 'control ears' to maintain peripheral awareness of the state of the overall system. Major incidents in EMD correspond approximately to hazards in aviation, in that they demand a shift of focused attention; however, just as the pilot needs to continue flying the plane while dealing with the hazard, so the allocator needs to continue dealing with routine incidents in the sector while addressing the needs of the major incident. The challenge in EMD is to design displays that enable the allocator to interleave these tasks well and maintain awareness of tasks (dealing with routine and major incidents), system state (e.g. locations and statuses of vehicles) and the environment (ongoing and new incidents). In contrast to aviation, where dealing with hazards is typically a different kind of activity from routine operation, in EMD, major incidents share many features in common with routine ones, except that they are more demanding, leading allocators to build up and work with a 'picture in the head' that enables them to plan how to deal with the incident more effectively.

Endsley and Smolensky (1998) discuss SA in air traffic control (ATC), another dynamic context in which operators have to keep track of many aspects of the situation in real time, including projected future locations. Like the EMD staff studied here, Endsley and Smolensky discuss ATC operators' use of the term 'picture' to refer to their mental models of the situation. Mental models are internal, simple, structural analogies of the world that support reasoning and problem-solving.

Mental models provide an account of human reasoning that moves away from the idea that people naturally reason logically (e.g. in terms of a propositional logic). While there are many different perspectives on the details of what mental models are (e.g. Johnson-Laird, 1983; Gentner and Stevens, 1983), there is broad consensus that they can be used to generate explanations (e.g. of why a system behaves as it does), support diagnosis (e.g. when something goes wrong with a system) or aid planning (of what to do to change the system in desired ways).

Endsley and Smolensky emphasise the important role of this mental picture in planning and controlling the flights of aircraft under their control. At first glance, it might appear that the 'picture' is the same concept in EMD and ATC. Is this so? In ATC, the 'picture' comprises current and projected configurations of aircraft in the sky; in EMD, the term is used to describe envisioning what is happening at and around the scene of a major incident. Thus, the 'picture' in EMD is less dynamic and also less complete than that in ATC: it is built up as information about an incident comes in, overlaid on pre-existing knowledge about the geography (road layout, etc.) of the area of the incident, and it evolves comparatively slowly as events at the scene unfold over minutes or even hours (depending on the scale of the incident). However, it shares with ATC the property that it is used to support planning.

In the ATC context, Endsley and Smolensky (1998) also discuss the role of automation in enhancing or reducing situation awareness. As discussed above, in EMD, SA encompasses external features of the system, such as vehicle locations, as well as internal ones (within the control centre) and features of the environment, such as incident types and locations. Dynamic external features are overlaid on a relatively static knowledge of the geography, in terms of road layouts, positions of hospitals and ambulance stations, etc.. There are both rapidly changing external features such as ambulance locations and the scenes of incidents and slowly changing ones, such at the availability of a particular facility at a given hospital or the locations of road works. Within the control room, SA is maintained through at least three modalities: vision, hearing and touch, including the physical placement and handing over of paper tickets. Much SA of external (outside the control room) information is maintained in the head, with comparatively little external (outside the head) support.

Endsley (1995) discusses the importance of expertise in developing and maintaining SA in dynamic situations, particularly in the use of pattern-matching mechanisms to rapidly understand the current situation by drawing on previous experience. Although less 'dynamic' than Endsley's case studies, expertise was found to be similarly essential in our study of EMD for developing SA and building a 'picture' of an incident. As discussed above, Endsley categorises SA in terms of three levels: perception of the elements in the environment, comprehension of the current situation and projection of future status. Endsley does not distinguish, as Wickens does, between the different elements (task, system, environment) to which SA might apply. In EMD, we have found that level 1 includes the locations of vehicles and incidents; level 2 the overall distribution of vehicles around the sector (including ensuring adequate coverage for all areas); and level 3 projecting vehicle distribution into the future and dealing with incidents.

Endsley's levels and Wickens aspects of the SA problem appear to be orthogonal; Table 2 shows our simultaneous application of both frameworks to SA in EMD.

	Level 1: perception of elements	Level 2: Comprehension of situation	Level 3: projection of future status
Task	R: Seeing outstanding jobs (emergency and urgent). M: Perception of incident description	R: Comprehending overall sector demands. M: Comprehending requirements of jobs.	R/M: Anticipating future vehicle demands.
System	R: Locations of vehicles. R: Status of vehicles. R: Crew requirements such as shift changes and meal breaks.	R: Comprehending overall system configuration (e.g. coverage of all areas), and areas of high and low demand.	R/M: Anticipating future resourcing demands. R: Anticipating future vehicle availabilities (e.g. coming free at hospital). M: Anticipating traffic flow around a major incident.
Environment	R/M: Gaining awareness of new incidents	M: Assessing nature and magnitude of incident. R: Comprehending overall sector demands.	M: Anticipating likely changes in a major incident.

Table 2. relating EMD to Wickens' and Endsley's frameworks. (R : routine incidents ; M : major incidents)

As shown in Table 2, it is possible to relate key elements of SA in EMD to both Endsley's and Wickens' frameworks. Some elements relate primarily to routine operations, for which awareness of incident details (the 'environment') is less important than awareness of the state of the 'system' – vehicles and their locations. Conversely, due to the responsive nature of EMD, it is difficult to project the future status of the 'environment' for routine incidents, except for pending jobs in the 'urgent' category, so projection of future status of the environment pertains mainly to major incidents.

System requirements for supporting SA

The discussion above provides a useful context for describing allocators' situation awareness in EMD. As shown, SA is selective, but systems need to support SA at the most critical times, when workload is highest – when there is both routine activity and also a major incident (or possibly more than one) developing. The need for SA represents a set of constraints on how a system's requirements should be implemented.

We illustrate this point with an example: the need to compare incident details between different calls to ascertain that they are indeed different incidents could not, at the time of the study, be easily done using computer support. Yet this process plays a significant role in assessing the severity of the situation, by bringing together different eye-witness accounts of the same event, and also for determining whether multiple calls are for the same incident. (Since they work with limited resources, it is important *not* to tie up vehicles unnecessarily on duplicate calls.) Allocators often lay out the printed job tickets in front of them to facilitate this visual comparison.

Thus, while it is necessary to have the required data to support the identified tasks, understanding how SA is developed and maintained within the context of the work can guide designers toward the provision of facilities that will enable the allocators to better perform their work.

A number of such strategies have been identified:

(i) Allocators develop an understanding of the situation by collating and integrating information from different sources (radio operator, tickets, computer system), different modalities such as aural ("control ears"), visual (written text) and touch (physical placement of tickets, and handing over of tickets), and over a period of time. The design of the working space and information resources is key to helping allocators maintain SA.

(ii) As noted above, allocators often visually compare and evaluate incident information from within the same incident and between incidents, for instance, by laying out the tickets on the table in front of them. They do this to ensure that calls to the same incident are correctly identified, to piece together the situation, and to assess the overall situation. Allocators manage multiple calls for an incident as a incident rather than as individual calls, e.g. the multiple calls that arrive for a major incident are bundled together, reviewed, and updated collectively as an incident rather than as individual calls. Whether on paper or an electronic system, allocators need to be able to do this comparison and integration of information from multiple calls.

(iii) Allocators often face uncertain information and verify the authenticity of calls by assessing characteristics of the incident against what they already know about similar types of incidents, e.g. call rates, number and type of casualties (they refer to this knowledge as '6th sense'), and by using 'control ears' to listen for key information from other allocators and dispatchers in the control room to corroborate information about the incident. This depends on both experience and good communications.

(iv) Allocators usually know which resources are nearest to an incident location. Since they constantly keep themselves updated about what each vehicle is doing and where it is located, they only need to glance at their box to confirm ambulance availability in the immediate vicinity and even further afield. They use their knowledge of the area to help them focus on the stations to assess, rather than having to assess availability at all stations. They look for the nearest available ambulance and then spiral their search outwards for the next nearest available, always ensuring adequate ambulance coverage in the region. In doing this, allocators make a number of trade-offs between nearness, time and incident severity. A well designed mapping system can or could support this activity, externalising much of the information known to allocators.

(v) Allocators develop a mental map of their area of operations that identifies key landmarks, one-way systems, main roads, obstacles such as rivers, hospitals, ambulance stations, and their locations in relation to each other.

(vi) Allocators constantly anticipate the immediate future scenario and cater for it by planning the jobs that an ambulance can go on to next. To help them remember and to communicate this plan to others at the sector desk, allocators physically place the ticket of a job that an ambulance is about to complete with the ticket for the next job. This requires good awareness of the situation and knowledge of intermediate or temporal resource states.

(vii) Allocators are rarely presented with all the necessary information neatly collated at the start of a major incident: they generally make plans based on incomplete information, and these plans are then modified as more information becomes available. They have to maintain awareness of the state of the incident, what resources have been sent, etc. over an extended period of time.

How representative are our findings about allocators at this control centre? Not all strategies were practised by all allocators in the study. Workers in complex socio-technical systems are often presented with multiple ways of resolving a problem and their choice of strategy is dependent upon situation factors such as workload. (Sperandio, 1978) found that air traffic controllers invoked different strategies of working as workload increased from low levels to high levels; while we have not explicitly studied changes with workload, we have shown that increasing workload leads to longer activation times, and have shown that SA demands increase with complexity of incident and with the number of incidents. In particular, we have found that allocators maintain SA of both the general situation within their sector (and sometimes further afield) and complex incidents.

These strategies raise the need for interfaces that present information in a manner that is compatible with the way the information is used for real-time decision making, planning and control and SA development and maintenance. The study has suggested the need for display designs that help the allocators keep track of the dynamically changing temporal aspects of the situation. We propose that screen designs should be guided by the Proximity Compatibility Principle, PCP (Wickens & Carswell, 1995). The PCP states that where there is benefit, information that is used together in a decision or a cognitive process should be integrated or presented together. This requires an understanding of what Wickens refers to as the mental proximity of the task, i.e. an understanding of how closely related or integrated the mental task is; and then being able to create a design that is reflective or compatible with the mental task proximity, or display proximity. When there is compatibility between the mental task and the display design, the PCP predicts that we can then expect performance improvements. This is the general approach we have taken to translate the strategies described above, as a representation of the mental task proximity, to derive guidance for displays that will exhibit high compatibility between display to mental task. We describe these as design guidelines and they are briefly presented next.

<u>Design Guideline 1: Integrate and collate related relevant information in a manner that allows visual comparisons that make use of quick glances.</u>
There should be minimal reliance on 'drilling down' for details, nor the need for comparing related relevant details between multiple windows. This is a sequential and time-consuming process. Instead, required information should be collated from different incident records or calls and presented in a *single* viewing space. For example, a user should be able to select records to compare and have the relevant details presented in a single window rather than having to drill down one record after another to compare relevant details. This approach reduces the high reliance on working memory which is error prone. This can reduce the time and effort needed to make comparisons of details between records.

<u>Design Guideline 2: Allow allocators to manage incidents rather than just calls.</u>
The display design should allow allocators to group related calls together as incidents. These are vital temporal operational relationships that should be supported in the information space. The displays should present sufficient call details from different calls for the allocator to readily determine whether the calls relate to the same incident, and should be able to quickly determine by visual inspection that ambulances have been dispatched to the incident and the identities of those ambulances.

<u>Design Guideline 3: Indicate the level of certainty in the information received.</u>
As described earlier, the information received by an allocator is often second or third party information. This means that the allocator cannot directly interrogate the caller to verify the information and to therefore make some assessment of the information. Therefore any initial

estimates about the certainty of the information should be conveyed with the call information and presented together with the call details.

Design Guideline 4: Allow a spiral visual search pattern to locate the next nearest ambulance available to an incident (location).

Displays that support a spiral visual search strategy differ from screens in current use in that screens currently present a list of the nearest ambulances "as the crow flies". The nearest vehicle as the crow flies can sometimes be the farthest due to intervening mountains, rivers, one-way road systems, or peak-hour traffic. It should present the job (incident) location, the ambulances available, likely to be available, could be made available (e.g. ambulances *en route* to pick up a non-critical patient to transfer to another hospital), and not available, that reflect the spatial relationship of the ambulances to an incident location. In this manner, displays can be made compatible with allocators' mental representations of their tasks and operational domains. Such display designs can reduce task response times by as much as 40% (Wong *et al*, 1998).

Design Guideline 5: Allow for assigning of temporary intermediate planning states and intentions.

Temporary planning states include states such as when an ambulance will be completing job A, and is being planned to directly continue on to job B. At the time of the study, such intermediate stages were reflected by physical placement of artefacts, e.g. job ticket A is placed over job ticket B, and their placement on the desk indicate that it is a task that is still outstanding, or when placed on the allocation box, is a non-verbal instruction to the radio dispatcher to carry out the task. Although very transient, these practices help allocators remember, plan ahead, and communicate intentions. Such details should be captured on the system and visually presented on the displays.

Conclusion

From this study, a number of observations can be made about SA in EMD at this control centre. They are:

(i) Decisions are not made in isolation, but within the context of a dynamically changing situation. Awareness of this situation is therefore crucial.

(ii) Senior EMD operators practise an 'information hub' strategy that allows them to be made aware of changes in the different areas and activities they control.

(iii) EMD operators who demonstrate an awareness of SA describe a mental model that consists of a static set of information (knowledge that does not change or changes infrequently, and that they need to know), and a dynamic set of information which they need to keep track of.

(iv) EMD operators need to integrate the pieces of information about the situation they receive from different sources, over a period of time, and through different modalities. Furthermore, when presented with major incidents, complications include ambiguous information and significant time pressures.

These factors collectively place significant pressures on the EMD operator's capacity to handle the large volume of information that is usually created during major incidents.

Allocators in this study referred to the knowledge of the situation as a 'mental picture'. This mental picture has several aspects of knowing: the external environment, the systems and the tasks. As the situation changes dynamically, the allocator has to keep up with it to build this picture, which is then used to evaluate and predict the outcome from their plans. Being aware of what is going on allows the allocator to anticipate what is likely to happen next and hence plan for it. Therefore, it is important to design systems that help the allocator keep abreast of the situation. SA is not the mental picture; rather, the mental picture is an outcome of the process of SA; it may be considered a snapshot of the state of events at a point in time. The mental picture, or the allocator's understanding of the situation, comprises a static, structural component and a dynamic, temporal component; separating information into structural and temporal components enables the creation of systems designs that can more specifically address the temporal needs.

Reflecting back on the methodology applied in this study, we recognise some of the weaknesses in the approach that plague all studies of SA. Endsley and Smolensky (1998) discuss the possibility of studying SA in air traffic control using controlled laboratory settings; practical constraints made this impossible in our study of EMD, so we relied on observations and verbal reports in naturalistic settings. This made it difficult to get reliable verbal protocols at times when the requirements of situation awareness are highest. In particular, in EMD, most of the task relies on verbal communication, so a think-aloud protocol would interfere with task performance, and the task is safety-critical, so it is not acceptable to distract operators during periods of high workload. As noted by Wickens (2000), operators also cannot speak of that of which they are not aware, so (by definition) shortcomings in situation awareness are very difficult to detect. Given these limitations, we believe that the selection of techniques applied in this study were as effective as possible.

The initial interviews and study of documentation provided a good overview of the official perspective on EMD; because EMD is a highly regulated domain, we found no substantive differences between the official (or 'front') and actual (or 'back') (Goffman, 1959) versions of practice. The analysis of performance data gave a perspective on workload that sharpened the focus of the subsequent interviews. The observations and interviews gave complementary, but not contradictory, views on the nature of EMD. As discussed above, the discrete nature of the job meant that there were time windows in which contextual interviewing was possible, but the safety-critical nature of the work made it impossible to probe in depth during such interviews. Conversely, the CDM interviews, which took place away from the workplace, were divorced from the work context, but made deeper questioning and reflection possible. Had this been set up specifically as a study of SA, some of the questions could usefully have focused more directly on aspects of SA, such as Endsley's (1995) levels; however, the rich data obtained in the course of this study proved sufficient for constructing the account of SA presented above.

This account has been compared to analogous accounts of SA in other naturalistic decision making domains such as aviation. In particular, we have shown that the frameworks of Wickens (2000) and Endsley (1995) are orthogonal, and that the various elements of SA for EMD can be understood in terms of the table constructed by combining the two frameworks. In doing so, it has emerged that SA for routine operations focuses mainly on levels 1 and 2 of Endsley's framework, and on task and system within Wickens' framework. In contrast, most of the features of major incidents demand SA at level 3 (projection of future status) and concern the environment. It seems likely that this is a point of contrast from domains such as aviation, where all levels of SA are required under most conditions; however, since this has not been explicitly discussed by researchers in that domain, it remains as speculation.

We have also shown how this understanding can be conceptualised as strategies, and how display design guidelines for future systems can be derived from these strategies. These design guidelines, based on the Proximity Compatibility Principle, briefly illustrate how the manner in which information is used in decisions can be presented in a manner that is more informative and accessible to allocators.

Different ambulance services around the world organise their operations differently, with different technical support for the various functions. Many will experience fewer major incidents than the ambulance service studied here. Nevertheless, by focusing on a domain in which SA has not previously been studied, we believe these findings about SA contribute to the overall understanding of SA in general, and particularly to the understanding of SA in EMD.

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