# Situation Awareness and its Implications for Human-Systems Interaction

***ABSTRACT***

*This paper describes the nature of situation awareness in the command and control of emergency ambulances in a large metropolitan centre. In a field study using the Critical Decision Method, situation awareness has been found to play a crucial role in ensuring that real-time decisions are made in the context of the situation. A descriptive model of how dispatchers interact with their control systems to develop and maintain this mental picture was developed. This paper proposes four challenges that systems developers must address when designing command and control systems for emergency ambulance dispatch management.*

## Keywords

situation awareness, human-systems interaction, field study, command and control, emergency ambulance, Critical Decision Method

## 1. INTRODUCTION

In this paper we describe a field study into the nature of situation awareness and its role in operational decision making in Emergency Medical Dispatch. Our study was situated in a large metropolitan ambulance service where we studied how dispatchers exercised command and control over emergency ambulances. The Critical Decision Method (Klein et al., 1989), a retrospective protocol analysis approach to cognitive task analysis (Hoffman et al., 1998), was used in the study. This resulted in a description of situation awareness, decision making, the strategies that dispatchers invoked in performing their jobs, and the difficulties they face in the current work environment. In this paper we will present the descriptive model of situation awareness in the command and control of emergency ambulances, and then discuss the challenges that this model presents the design of human-systems interaction.

Situation awareness has been defined 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." (Endsley, 1995). Situation awareness in emergency medical dispatch is the state of being aware of the goings-on in and around the area being covered by ambulances, and of its significance to current ambulance operations. This understanding, and the ability to predict the future state of ambulance control, will help dispatchers cater for possible eventualities. This appears to play a significant role in the making of good decisions in emergency ambulance control.

Emergency Medical Dispatch, EMD, is the "reception and management of requests for emergency medical assistance in an emergency medical services (EMS) system" (Clawson & Dernocoeur, 1998, p662). EMD may be functionally divided into two areas: Call taking and prioritisation, and the command and control of emergency ambulances. In this study, we were primarily concerned with the command and control aspect, i.e. the planning, directing, coordinating and controlling of ambulances to get the right medical care to the right place and at the right time in order to improve the patient's chances of survival.

## 2. BACKGROUND

The ambulance service studied is one of the largest in the world, responding to over 3200 emergency calls every 24 hours. This large volume of calls presents particular challenges in operations control. EMD is managed from a single control room which is divided into two physical areas. At one end, the area is designed for up to 22 call-takers to receive '999' emergency calls. Call takers receive and prioritise all emergency calls between those that are immediately life-threatening and those that are not. At the other end of the room, as many as 35 dispatchers work at seven sector desks, representing the seven ambulance areas of operation. Each sector has a sector allocator who is in charge of the sector's operations, a radio operator and one or two telephone dispatchers who assist the allocator. The allocator is responsible for all dispatch decisions within the sector, while the radio operator maintains radio contact with all ambulances that are on the move. The dispatcher generally communicates with ambulance crews that are on station.

Once information from a call is entered into the computer system, the information is immediately available to the allocators and their teams at the sector desks. Once the location of the incident is known, the call is directed to a specific sector. Details of the call are printed out onto paper "tickets", which become the means by which incidents are managed. Ambulances are assigned and this information and additional updates are recorded by hand on the ticket. The ticket is placed in a slot in the allocation box. The placement of the tickets in the slots provide cues about the operational status of ambulances.

## 3. METHODOLOGY

The study employed a cognitive task analysis approach called the Critical Decision Method (Klein et al., 1989) (Hoffman et al., 1998) which used a retrospective protocol analysis technique. 13 allocators, radio operators, and dispatchers were interviewed on a one-to-one basis for about one and a half hours each, using a participative approach (Wong et al., 1997). We also conducted a cognitive ethnographic study (Hollan et al., 2000) to understand the meanings encapsulated in the artefacts of the work domain. In this paper, we focus on the results from the Critical Decision Method part of the study. The interview transcripts were analysed using a Grounded Theory approach (Glaser & Strauss, 1968). The analysis included looking for cues and considerations, knowledge needed, likely mistakes and how they maintained situation awareness. When compared across interviews, a number of common themes emerged. Among the first themes was a description of goals and sub-goals that described the types of decisions being made in the human-system interaction. These goals became our framework for further structuring and analysing the data. Observations from the interviews were used to ground the resulting theoretical conceptualisation of the nature of human-system interaction in EMD.

Key findings from the study include a naturalistic decision making model of the naturalistic work domain of emergency ambulance command and control (Wong et al., 2000). This model shows three decision process – situation assessment, planning, coordination and control – embedded within a situation awareness process that the allocator engages in to keep constantly abreast with the situation. This decision model will not be discussed in this paper but it is within this context that situation awareness will be discussed next.

## 4. THE NATURE OF SITUATION AWARENESS IN EMD

The awareness that Emergency Medical Dispatchers (EMDs) have in and around the processes they control situates the decisions and actions that they make. It enables them to optimise their use of resources, and it enables them to plan ahead and cater for contingencies. Without good situation awareness, they would be making dispatch decisions in a vacuum. In this section, we briefly explain the concept of situation awareness as described by the EMDs, and why it is necessary. We provide a descriptive model of how they develop and maintain it, the cues they attend to, the knowledge needed to successfully develop and maintain it, and some of the difficulties encountered in doing so.

During the study, one allocator described this phenomenon as "… a picture in your head of what's going on …" (1/1174). Another described the mental picture of an incident scene at a public swimming pool:

> "… you can just imagine a swimming pool with lots of kids walking around, ambulances, people collapsing around." (6/766).

This mental picture in not limited to the situation at the scene, but extends to the situation in the sector.

> "… you should be … aware of what's going on and start thinking ahead, 'cos if there (is something) going on then you gotta start pulling the resources in and everyone is gonna start getting you … around it so you know, you have got to be aware of that." (1/750-753)

Situation awareness gives EMDs the contextual understanding that enables them to make decisions that cater for potential problems, e.g. possible congestion, and better resource utilisation based on the awareness of the stage each ambulance is at in carrying out its job.

This mental picture is observed to be made up of two parts. The first is the knowledge of the area:

> "Um…you must know the area. " (3/1458-1459)

Knowledge of the area may be explained as a static mental model (Endsley, 1995; Johnson-Laird, 1989) of the structural relationships between the components of reality being modelled. These relationships include key features and landmarks such as major one-way streets, locations of buildings, hospitals, rivers and bridges. They then combine this static knowledge of the area with the second: A dynamic knowledge of ambulance activity, i.e. where ambulances are, where they are going, the stage they are at, will be at, and could be at in their jobs, the location of the incidents and the priorities and extent of each emergency. By combining the static and the dynamic knowledge, EMDs "see" this mental picture.

But how do EMDs develop and maintain this mental picture? Allocators behave as *information hubs*. They are at the centre of all information flowing within the sector. Information is constantly being "pushed" to the allocators who are also "pulling" information by requesting it or following up on instructions, as described in the following excerpt:

> "Um, well I know everything that's going on, because all the information comes through me. (5/1985) … anything that happens on scene comes through the radio or if it comes via the landline it will come via the dispatcher and I am told, or if there's anything that I want to know then it will…the radio operator, I will say to Ange, will you ask him where, um…where this Poplar crew is, or…or whatever I want to know that's relevant." (5/2039-2042)

As information hubs, they are the focal points for a wide variety of information. One of the prime activities is to collate the information into meaningful streams. This is difficult as the information often come from different sources, over several minutes, and interleaved with information about other incidents. The allocators therefore need to distinguish relevant information from information about other simultaneously occurring incidents. Information for one incident can also come from different callers,

> "…as in Brixton, and one…one caller will say, oh there's a woman bleeding from her hand…. One caller will say, oh there's a man lying on the floor and I think he…he's not moving. Um…one caller will say, oh there's broken glass everywhere and I think it's hit a few people. Everybody will tell you different." (5/953-959)

Other information that the allocator must collate comes from conversations going on across the room. Listening in to such conversations is a special skill called "control ears" which EMDs describe as:

> "… it means that you can hold a conversation and someone will talk to you and you can listen to your commander when you are talking on the phone" (6/781-782)

They are able to selectively tune their attention to listen for special things such as,

> "… 'You've got a train crash as well huh?', ' Where's yours?', 'We've got one here,' and then we see how it links up." (2/263-265)
>
> "Because um…when vehicles become available, in my sector, but from another sector, (the other sector allocator) will always call over and say, I've got the Malden crew at West Middlesex." (3/1337-1339)

Because they are aware of relevant things going on around them, they can start planning or initiating appropriate actions even before being instructed.

> "…you can hear things that are going on around you, and you start to do it without even being asked to do it." (8/1896-1897)

Sources of additional information include written notes on the job ticket, the spatial positioning of these tickets, and the physical handling of tickets that indicate handing over of a job to another dispatcher. Of particular importance is information coming through the radio operator about on-road developments that

> "… tells me what's going on, and then I can get on with my job." (5/2179)

On-road information tells the allocator about the emotional state of ambulance crews, especially after traumatic cases. This indicates whether they are emotionally capable of dealing with the stresses of the next case.

While experienced EMDs were observed to be very capable of creating a mental picture of the situation, they face enormous challenges in collating and integrating relevant information from different sources, different modalities and over a period of time. Information needs to be incrementally integrated into the mental picture, updating it with changes, and discarding information that is no longer relevant,

> 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, 'cos you are only talking verbally over the radio, you have not got a picture of it, you can't see what's going on, so you can only talk and you can only imagine what's going on (1/1713-1719).

Furthermore, the process is made more difficult because EMDs are heavily reliant on third party information received from the crews, police and fire, and members of the public at the scene.

> P: … Because you can't see what's going on, it's very difficult. You can only go by what they're saying, and it's really, really difficult. (1/1187-1189)

In such situations, there is always the issue of reliability of information and correctness of the interpretation and assessment of the person reporting the information.

As described above, situation awareness plays a significant role in the decision making process of emergency ambulance dispatchers. Collectively, these observations present a number of challenges for designing systems that cater for the development and maintenance of situation awareness for the command and control of emergency ambulances. These challenges are summarised next.

## 5. CHALLENGES FOR HUMAN-SYSTEMS INTERACTION DESIGN

In some of the earliest discussions about situation awareness, others have argued for the central role that situation awareness plays in command and control decision making (Wohl, 1981). The results from our study reinforce that argument and extend it by describing the specific activities involved in developing and maintaining situation awareness in EMD. This descriptive model has helped us understand the key issues and raises challenges which systems developers must address when designing command and control systems.

Challenge 1: How should the requirements for "soft" phenomena such as situation awareness be designed? 'Soft' phenomena, are often difficult to identify and describe and, as such, have been difficult for systems analysts to define the requirements for. The requirements for such phenomena are not as objective as defining a data model for a system. For example, the specification for software usability has traditionally been difficult to define, but in now acknowledged by software engineers and referred to as 'non-functional' requirements (Vliet, 2000). These represent the soft aspects of a system, such as the form in which information that represents processes being controlled should be portrayed. Yet it is the forms of these representations that often present users with difficulties. The form that the portrayed information should take in EMD must address the key user strategy of *information hubs*. Designs must reduce the effort needed to build and maintain situation awareness by helping the EMDs collate and integrate information from different sources, using different modalities and over a period of time. How do we bring together information that is heard through conversations, information that is embedded in tactile or spatial arrangements of physical artefacts, and even information tracked by present computer systems, in a manner that would help the EMDs tell a story to describe their mental picture of the situation?

Challenge 2: We need to have a better understanding of the structural and temporal relationships between operational concepts, entities, functions and goals relevant to developing and maintaining situation awareness in EMD. Various cognitive work analysis methods (Rasmussen et al., 1994; Vicente, 1999) have been successfully applied to a number of physical and causal systems to identify and represent the structural invariants inherent in these systems. Such techniques have been applied with varying degrees of success to systems in intentional domains such as command and control (Hajdukiewicz et al., 1999; Wong et al., 1998b). What is emerging from this stream of work in cognitive engineering is a better understanding of what the cognitive work analysis tools need to model. Temporal issues such as intermediate states of ambulances discussed earlier, e.g. not available, will be available, could be available, and available, are operational concepts that EMDs use routinely in planning and decision making. Such issues need to be factored into the analysis of cognitive work in intentional domains. Such 'soft' aspects of what EMDs do so naturally also need to find appropriate representations in systems.

Challenge 3: Closely associated with identifying the knowledge for cognitive work, is the definition of the boundary between knowledge that EMDs simply need to know, and knowledge that is constantly changing and therefore better left in artefacts that populate the physical domain of the EMDs. This division is known as knowledge in the head and knowledge in the world (Norman, 1990). Having all necessary ambulance operational control knowledge in the head would be extremely useful as it would mean the EMDs would, for example, know where each ambulance is and what each is doing, and what current traffic conditions are. This would make dispatch decisions very fast and efficient. Unfortunately, such a level of expertise is difficult to achieve, so much of this information has to be represented in artefacts in the EMDs' world. For example, the development of computerised map-based systems for ambulance dispatch is a means of externalising the mental representations of emergency operations. This has the advantage of off-loading knowledge in the head into knowledge in the world and is useful for supporting novice EMDs, but has serious consequences if the system fails as the operator has become dependent on it. Where should this boundary be and what should it depend upon?

Challenge 4: Finally, how do we portray the information? Poorly portrayed representations of processes and the associated control information can lead to problems such as taking more time to collate information, high information access cost which results in the users not being able to access needed information within the short time frames available, and even poorer or incorrect understanding of the situation. These difficulties when experienced in the context of dynamic, time pressured domains, and especially under high workload conditions, can lead to diminished user performance. In the case of an ambulance service, such deficiencies can mean ambulances taking more time to reach a patient, reducing their chances of survival. Research in the representation of causal systems has shown how ecological perception concepts (Vicente, 1992), emergent features and configural displays (Buttigieg & Sanderson, 1991) have benefitted users of such systems in being better able to detect and diagnose system problems. Other studies in command and control of emergency ambulances (Wong et al., 1998a) have shown that dispatch performance can significantly improve if the representation is well tuned. The challenge here is to bring the understandings from the analysis of cognitive work, e.g. the information hub strategy, and the knowledge boundaries, together in a manner that systems designers can use to map (Bennett et al., 1998) important characteristics and meanings from domain to representational designs.

## 6. CONCLUSION

In this paper we have presented our findings about the nature of situation awareness in the command and control of emergency ambulances from a field study at a metropolitan ambulance service. The descriptive model of situation awareness briefly discussed has provided us with insights into the 'soft' aspects that must be addressed when designing command and control systems. This has presented four challenges: the need to support the information hub strategy, the need to develop a better understanding of the structural and temporal relationships between operational concepts and entities, the need to know where an appropriate boundary between knowledge that EMDs must know and knowledge that can reside externally, and finally, how the mental representation of situation awareness needs to be supported by appropriate portrayal of this information. Finally, this paper has shown how a descriptive study can help us develop a theoretical conceptualisation of the human-work interaction in the dynamic operational domain of command and control of emergency ambulances.

## REFERENCES


Bennett, Kevin B., Nagy, Allen L., & Flach, John M. (1998). Visual displays. In M. G. Helander, T. K. Landauer, & P. V. Prabhu (Eds.), Handbook of Human-Computer Interaction (2ed ed., 659-696). Amsterdam: Elsevier Science B.V.

Buttigieg, Mary Anne, & Sanderson, Penelope M. (1991). Emergent features in visual display desing for two types of failure detection tasks. Human Factors, 33(6), 631-651.

Clawson, Jeff J., & Dernocoeur, Kate Boyd. (1998). Principles of Emergency Medical Dispatch. (2ed ed.). Salt Lake City, Utah: Priority Press, The National Academy of Emergency Medical Dispatch.

Endsley, Mica R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1), 32-64.

Glaser, Barney G., & Strauss, Anselm L. (1968). The discovery of grounded theory: Strategies for qualitative research. London: Weidenfeld and Nicolson.

Hajdukiewicz, John R., Burns, Catherine M., Vicente, Kim J., & Eggleston, Robert G. (1999). Work Domain Analysis for Intentional Systems Proceedings of Human Factors and Ergonomics Society 43rd Annual Meeting 1999, 333-337.

Hoffman, Robert R., Crandall, Beth, & Shadbolt, Nigel. (1998). Use of the Critical Decision Method to elicit expert knowledge: A case study in the methodology of Cognitive Task Analysis. Human Factors, 40(2), 254-276.

Hollan, James, Hutchins, Edwin, & Kirsh, David. (2000). Distributed Cognition: Toward a new foundation for human-computer interaction. ACM Transactions on Computer-Human Interaction, 7(2), 174-196.

Johnson-Laird, P.N. (1989). Mental models. In M. I. Posner (Ed.), *Foundations of Cognitive Science* (469-499). Cambridge, MA: Lawrence Erlbaum Associates.

Klein, Gary A., Calderwood, Roberta, & Macgregor, Donald. (1989). Critical decision method for eliciting knowledge. IEEE Transactions on Systems, Man and Cybernetics, 19(3), 462-472.

Norman, Donald A. (1990). The design of everyday things. New York: Doubleday.

Rasmussen, J., Pejtersen, A.M., & Goodstein, L.P. (1994). Cognitive systems engineering. New York: Wiley.

Vicente, Kim. (1999). Cognitive work analysis. Mahwah, NJ: Lawrence Erlbaum.

Vicente, Kim J. (1992). Multilevel interfaces for power plant control rooms II: A preliminary design space. Nuclear Safety, 33(4), 543-548.

Vliet, Hans van. (2000). Software Engineering: Principles and Practice. (2nd ed.). Chichester, England: John Wiley & Sons Ltd.

Wohl, Joseph G. (1981). Force management decision requirements for Air Force tactical command and control. IEEE Transactions on Systems, Man, and Cybernetics, SMC-11(9), 618-639.

Wong, B.L. William, Blandford, Ann, & Fields, Bob. (2000). Emergency Medical Dispatch at the London Ambulance Service: Report prepared for the Chief Executive, London Ambulance Service. London, UK: Middlesex University.

Wong, William B.L., O'Hare, David, & Sallis, Philip J. (1998a). The Effect of Layout on Dispatch Planning and Decision Making. In H. Johnson, L. Nigay, & C. Roast (Eds.), People and Computers XIII, HCI '98 Conference (221-238). Sheffield, UK: Springer, in collaboration with the British Computer Society.

Wong, William B.L., Sallis, Philip J., & O'Hare, David. (1997). Eliciting information portrayal requirements: Experiences with the Critical Decision Method. In H. Thimbleby, B. O'Conaill, & P. Thomas (Eds.), People and Computers XII, HCI '97 Conference of the British Computer Society Special Interest Group on Human-Computer Interaction (397-415). University of West England, Bristol, UK: Springer.

Wong, William B.L., Sallis, Philip J., & O'Hare, David. (1998b). The Ecological Approach to interface design: Applying the Abstraction Hierarchy to intentional domains. In P. Calder & B. Thomas (Eds.), Designing the Future: Proceedings of the Eighth Australian Conference on Computer-Human Interaction OzCHI'98 (144-151). Adelaide, Australia: IEEE Computer Society Press.