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William B.L. Wong
David O'Hare
Philip J. Sallis

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Department of Information Science
University of Otago
P O Box 56
Dunedin
NEW ZEALAND
Fax: +64 3 479 8311
email: dps@infoscience.otago.ac.nz
www: `http://divcom.otago.ac.nz:800/com/infosci/`

A Goal-Oriented Approach for Designing Decision Support Displays in Dynamic Environments

William B.L. Wong
Department of Information Science
University of Otago,
Dunedin, New Zealand
william.wong
@stonebow.otago.ac.nz

David O'Hare
Department of Psychology
University of Otago,
Dunedin, New Zealand
ohare@psy.otago.ac.nz

Philip J. Sallis
Department of Information Science
University of Otago,
Dunedin, New Zealand
psallis@commerce.otago.ac.nz

Abstract

This paper reports on how the Critical Decision Method, a cognitive task analysis technique, was employed to identify the goal states of tasks performed by dispatchers in a dynamic environment, the Sydney Ambulance Co-ordination Centre. The analysis identified five goal states: Notification; Situation awareness; Planning resource to task compatibility; Speedy response; Maintain history of developments. These goals were then used to guide the development of display concepts that support decision strategies invoked by dispatchers in this task environment.

Keywords: Critical decision method (CDM), cognitive task analysis, cognitive engineering, ambulance dispatch, command and control, information portrayal, display design, decision support.

Background

The Critical Decision Method (CDM) [1] was the cognitive task analysis technique used to elicit the information portrayal requirements of ambulance dispatchers working at the Ambulance Co-ordination Centre of the New South Wales Ambulance Service in Sydney, Australia. Five dispatchers were interviewed using the CDM and their responses were transcribed and analysed. The objective of this study is to identify the critical features and the higher order constraints of the ambulance dispatch process and then to use them to inform the design of how information should be portrayed to support decision making in naturalistic decision making (NDM) environments. It is believed that there will be improvements in display effectiveness by making visible to the user the higher order constraints or system goals states [2] and represent the system's reasons for proper functioning [3]. This notion underlies the philosophy of the cognitive engineering approach to system design [2, 4-6] and it is for this reason that other cognitive task analysis techniques such as KAT/TKS [7], and GOMS[8], were deemed inappropriate.

NDM environments may be described as [9-12] ill-defined problem situations in which conditions are constantly changing, where decisions are inter-related such that the outcome of an earlier decision will influence the way the next decision in the sequence is made. There is also a significant time-pressure to decide and act quickly because delays can cost lives, or because there are a large number of events to attend to in a short time frame. There are high stakes involved. A wrong decision can have severe consequences and possibly loss of life. Military and police command and control centres, emergency co-ordination centres, and nuclear power plant control rooms are examples of NDM environments.

The Sydney study represents the second in a series of sites to be investigated. The first dispatch centre studied was the Southern Regional Communications Centre of the St John's Ambulance Service based in Dunedin in the South Island of New Zealand [13]. The New Zealand sample provided an environment to study how dispatchers managed a small service stretched over a very large area, while the Australian sample afforded a comparison of how dispatchers managed a large service over a relatively small area. Before describing the results of the study, we will briefly describe the Sydney environment and the CDM technique used in the study.

The Ambulance Co-ordination Centre, Sydney

The Sydney Ambulance Co-ordination Centre is responsible for two rescue helicopters and about 130 ambulances deployed across 45 stations in the Sydney Division. The division is responsible for operating within an area of approximately 14,000 square kilometres, serving a population of 4 million. The Division is divided into five areas: The East Area, extending southwards from downtown Sydney to Botany Bay; the South Area covering the coastal areas south of Sydney International Airport; the South-West Area covering the inland areas south-west of Sydney to the Blue Mountains; the West Area covering the inland areas from Paramatta through to the Blue Mountains; and North covering the coastal block north of Ryde and Manly past the Ku-Ring-Gai Chase National Park to the Hawksbury River. The Centre receives about 295,000 emergency calls annually. In November 1995, the Centre responded to between 960 and 1264 emergency calls daily.

Although the Centre is in the process of computerising its activities, call-takers and the dispatchers were still operating manually in December 1995 when the study was conducted. The call-takers would receive the phone call and write down the details on a particular job slip depending on the nature of the request, e.g. yellow slips are for emergencies, and white slips are for routine medical transfers. Once the information has been recorded on the slip, the call-takers place the slip on a conveyor belt and it is then sent to the dispatcher responsible for the area in which the incident occurred. The slip arriving at the dispatcher's segment of the conveyor belt serves as a notification of an job.

The dispatcher would then pick up the slip, read it, record the time it was received, stamp a case number to it, and dispatch an appropriate vehicle to the job. Dispatchers could then be observed shifting different coloured job slips from slot to slot on the dispatch board as they responded to various emergencies and routine tasks.

The dispatcher for each area has in front of him or her a dispatch board comprising vertical slots (see Figure 1). Each vertical slot represents whether an ambulance is: On-station - to hospital - from hospital - out of area - cars returning - on case. A stage which is not included in the slots is the "at hospital" stage, and this information is represented by placing the assigned job slips on the right hand-side of the desk. The use of positioning to indicate meaning was also observed in the air traffic control domain where flight strips placed in a particular way on the flight progress board indicated information such as speed, position, abnormal flight, as well as what has been done and what remains to be done [14].

Figure 1 Area Coordinator's Dispatch Board

Ambulances are represented by represented by little plastic clips on which the vehicle's radio call-sign is written. If the vehicle is available, it will be clipped on the top slot of the dispatch board. When assigned, the plastic clip will be tagged to the job slip to which it has been assigned. As the job progresses through its various stages, the slip with the plastic clip will be moved from slot to slot until it is available and back on station.

The Methodology

The investigation was based on Klein's Critical Decision Method [1] or CDM. The CDM is essentially a retrospective verbal protocol interview technique, and a method for organising and analysing the data resulting from the interview. This method has been applied successfully in a variety of naturalistic decision making environments. For example, to elicit information portrayal requirements and to re-design the displays for decision makers in the combat information centers of AEGIS battleships [15], and to elicit perceptual cues used by expert nurses in neo-natal intensive care units [16].

During the interviews the five dispatchers were each asked to think back to a particularly memorable ambulance dispatch incident which they had participated in. As they described the decisions made and the actions taken, they were also probed for cues that they used or referred to during that incident, and the factors they considered while making that decision. These factors could then be used to infer the kinds of decision strategies invoked during that process [11, 15].

After transcribing the interviews, each transcript was indexed with a piece of software called NUD*IST™ [17] which is used for qualitative analysis. The transcripts are then analysed in five stages.

- Draw up a decision flow diagram of each incident. The incident is studied and the decision flow is illustrated along a horizontal timeline. The vertical dimension of the decision timeline is used to document how the decision was made, what cues or factors were considered in the process, and the outcomes of that process.
- Summarise each incident. The incident is extracted from the transcripts, and summarised into a page as compared to the 10 to 15 pages of the original transcripts.
- Identify and analyse the cues, situation assessments and courses of action for each incident. The cues, situation assessments and courses of action, the rationale and goals are subsequently identified and documented in a table that is based on the following model of how cues relate to decisions, how the cues were used, what factors were considered, and the purposes of their actions (see Figure 2).
- Identify goal states. The Decision Analysis table is further studied with the objective of identifying goal states of the interviewee at each stage based on the actions. These goal states are the higher order goals or constraints that each decision is targeted at achieving.

- Examine common goal states and their cues and decision strategies used. In this final stage of the analysis, the common goal states, cues, decision strategies of all the incidents are compared to reveal commonalities or patterns in the way goal states are achieved.

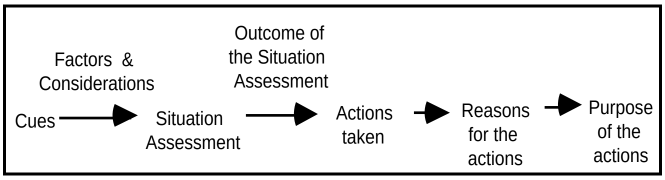

Figure 2 Data Analysis Process

The first four stages of the analysis are performed on individual incidents. The last stage is performed across all the incidents. This entire procedure is illustrated in Figure 3 (see [18] for details).

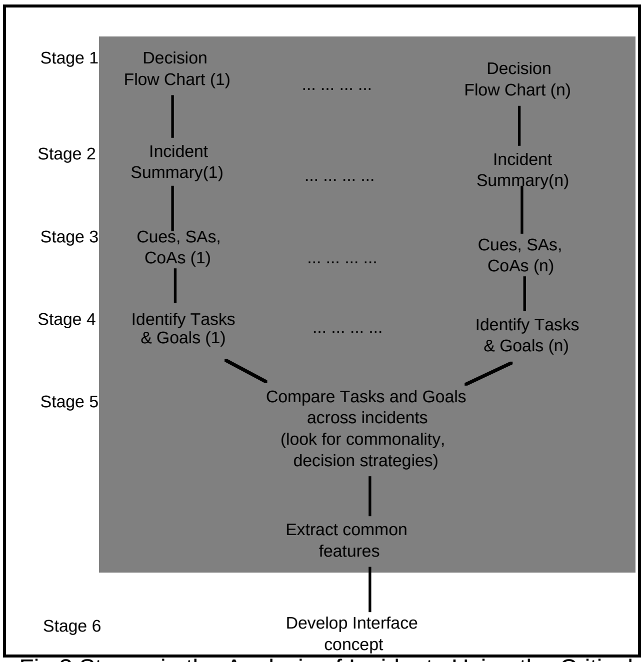

Fig 3 Stages in the Analysis of Incidents Using the Critical Decision Method

Once the nature of the decisions have been understood, interface concepts that help achieve the goal states are then developed. In the next section we will present the goal states that were identified and where applicable, the associated display concepts.

Goal States , Observations and Implications for Design

Rather than report on the specific findings from the analytical procedure described above, this paper will instead report on the identification of the goal states [19] and how these goals guided the development of several design concepts.

Finding commonality between the purposes of actions carried out in each case led to the identification of the following goal states:

I Notification of emergency
II Maintain situation awareness
III Planning resource to task compatibility
IV Speedy response
V Maintain history of developments

During the analysis, each goal state was examined in context of each interview. We investigated how the cues were used in assessing the situations and how courses of action were decided upon within the constraints of the higher order goals. The insights we gained from this analysis lead us to conclusions about how displays need to be designed to make visible to the user the higher order constraints or goal states of the process.

We will now discuss what these goal states mean and their associated implications for design.

I. Notification of emergency

This goal state represents the need to be notified quickly of any emergencies. In each incident, the dispatchers were notified by the emergency yellow job slip arriving in their respective segments of the conveyor belt system. This segment is immediately next to where they are seated. Because of the way the conveyor belt is made, job slips arriving in the respective segments were heard to make a scratchy noise which serves to alert the dispatcher to its presence. However, this method of notification was also observed to have gone unnoticed because of ambient noise or due to the dispatcher attending to other competing activities, e.g. informing ambulances of and recording the times when they report in, also known as the 'talking clock'.

Another activity that occurs at this time is the reading of the job slip to determine the nature of the emergency. As the call-taker and the dispatcher not the same person, the dispatcher can only rely on the information on the job slip to diagnose the situation.

II. Maintain situation awareness

Situation awareness may be defined as the "… development and maintenance of a highly dynamic mental representation of critical aspects of the … environment." [20] (p113). Although this term originated from and is frequently used in military aviation, the concept of being aware of what is going on is equally applicable in most if not all dynamic decision making environments. Some evidence of this goal state, identified during the analysis, is taken from the different cases and presented below:

Make colleagues aware of the potential disaster by shouting across the room.

To develop a mental map of where each unit was in relation to the incident in the next 10 minutes.

Keep track of all other activities going on at the same time to enable planning and re-deployment of resources as the situation changes.

A snapshot picture so that you know what's available, know what to send

Being aware of what is going on around them is important as it enables the dispatchers to make decisions that take into account situational factors and constraints that may influence how resources are used not just in their specific areas of responsibility, but across neighbouring areas. Situation awareness appear to facilitate:

(a) co-ordination of activities across different areas
(b) global optimisation of resources across areas of responsibility
(c) checking with one another to ensure compliance with instructions.

(a) Co-ordination of activities. In order for the Floor Supervisor to know what is going on in the various regions, he has to go around asking each dispatcher where each particular resource is and what they are doing. Because an awareness of what is going on in one region may affect outcomes and resource allocation in another region, dispatchers and supervisors are constantly checking with each other to maintain a *shared awareness* of the situation. This is evidenced in the transcript below.

Because the flow of information is a bit awkward in that I have to go to each controller and ask him where a supervisor is or a particular vehicle is, and then I have to go back and report to the senior supervisor. 595

He has to employ an active search strategy in order to locate the necessary information to plan or to allocate resources. A search strategy describes the actions a person needs to take in order to acquire the information he or she needs for a decision. An active search strategy indicates that the person had to move away from his immediate workstation, or to embark on a series of protracted actions in order to locate the information that is required. A passive search strategy on the other hand indicates that the information is readily available, e.g. in the head or readily on the computer display, and may be accessed without embarking on a lengthy set of procedures. The floor supervisor needs to walk over to and ask each controller for the information he requires. This will be an inefficient procedure during busy periods, as the dispatcher that he needs to help will be the dispatcher he needs to speak with in order to gain an understanding of the situation.

Implications for Design 1: This leads to the display requirement for a design that supports the notion of shared awareness of what is going on in the various areas that he is responsible for. Such a requirement suggests a need that information about the situation in each area of responsibility be readily available to the supervisor, preferably at the touch of a key, to show an integrated picture of the status of all resources. Such a display feature can be extended to dispatchers as well as it can be used during times when vehicles need to be coordinated between dispatchers from different areas.

(b) Global optimisation. The dispatcher often needs to understand what resources are available globally before he can plan how he will deploy the vehicles in a major incident. He or she cannot make a deployment plan in absence of global availability information. He or she also needs to know what jobs are outstanding so as to trade-off emergency and medical cases. Also, in considering what is available throughout the region, the dispatcher then focuses on what is within the immediate area of the incident in order to attain the other goals of speed of response, and to plan for the balancing of coverage in the immediate area. Global availability information helps the dispatcher globally optimise resources, i.e. a balanced deployment of resources suggests an integrated display across different areas of responsibilities.

Implications for Design 2: The above observation also suggests a need for *shared awareness* of the global resource situation. This is to facilitate resource sharing and resource planning. The notion of global availability has been somewhat implemented in the design of the St John's Computer Assisted Dispatch System [13]. It shows the following information:

- ambulances available: on station,
- available: at hospital or returning from the hospital or scene
- not available: on a job.

However, the display does not support forward or real-time planning because the display cannot portray subsequently planned tasks other than the one already assigned to a vehicle.

(c) Ensuring compliance. In team-based environments such as the Sydney Ambulance Co-ordination Centre, decisions made by senior members of the team directing the situation always need to be followed up on. This is to firstly ensure that assigned tasks are being implemented, and secondly to monitor if performance is in line with goal expectations. In life-critical situations checking to ensure that decisions are being implemented is even more important as the outcome of one decision often influences the way subsequent decisions are made. In one situation reported, the interviewee indicated that a significant amount of checking is performed.

… everybody checks everybody else up here. 628

So if a controller made a mistake, I would have picked up on it. 629

If I had made a mistake, the senior supervisor would have possibly picked up on it. 630

The interviewee also gave an example of how this checking is performed:

> S Alright in any given situation such as this one, you know, the senior supervisor would have said to me, "Have you got a supervisor going?" I would have gone across to the controller and said, "Get your nearest supervisor going. Who is it? Where is he?" 642
>
> I would have then walked back across the room and report this to the senior supervisor, "The supervisor is going from Penrith Station in Alpha-whatever car." And then I would travel all the way across the room and said, "Where are the SCAT officers?" I would then go back and said, "Two SCAT officers responding." So, the senior supervisor is aware of all the information I'm aware of that the controllers are aware of. So, hopefully we are all aware of the same thing. 643

In this case the information that is communicated is information about decisions, and the status of these decisions rather than resource-oriented information cited in an earlier example where the goal is to know where each ambulance is and what it is doing.

Much of the information about decisions and their status is not recorded in the system. Instead it resides in the heads of the dispatchers and supervisors. Because of the dynamic nature of the situations being controlled, these people are likely to make mistakes or slips as the result of stress or lapses of memory as the number of incidents they need to manage concurrently increases.

Implications for Design 3: This raises the need for a display that supports the recording and sharing of the outcomes of planning and dispatch decisions and the status of these decisions as they proceed from stage to stage. For example, it is possible to indicate that an ambulance has been activated, that it has left the station and enroute to the accident. Similarly it is possible to record with a single mouse click, that on-road supervisors have been activated and are on their way, or that designated SCAT personnel have been notified and are in the process of forming a team.

III. Planning resource to task compatibility

This goal state is about determining what the needs of a situation are, and to find an appropriate match between available resources and the needs as indicated by the following statement:

> "The goal would be to send the correct amount of ambulances to cope with the situation without shortfaling the area that aren't involved." (361) and "You don't want to send everything out of one area." (116) so that you will not be able "… to cover emergencies that are still going to happen … (117. 123)

Matching of the resources to the task requires some degree of planning, and in the study this goal state can be associated with five planning activities:

(a) Locating available resources
(b) Translating needs into resources to send
(c) Planning ahead
(d) Minimising disruption to on-going activities
(e) Planning to fill gaps in ambulance coverage

(a) Locating available resources. In one of the interviews, the dispatcher had to locate and assemble a team of specially trained ambulance officers for a difficult rescue situation. In order to locate these SCAT (Special Casualty Access Team) qualified-officers the dispatcher had to move his attention away from his dispatch board and retrieve a paper file from his desk which contained the daily staffing schedule. This schedule documented the duty personnel assigned to each ambulance and station. It also had an indication of the qualifications that each duty personnel had. This information was not readily displayed on the ambulance tags displayed on the dispatch board. Having identified the SCAT officers, he then had to determine which of these officers were closest to the accident scene. Because the appropriate officers were part of separate double crews at two different stations, these crews had to be disbanded (as the industrial relations agreement did not allow single-crew operations) in order to establish one SCAT Team.

This procedure is inefficient because the information that is used together in a decision is not portrayed together. It also contravenes Wickens' Proximity-Compatibility Principle which states that "…to the extent that information sources must be integrated, there will be benefit to presenting those dimensions in an integrated format." [21] (p98). Thus the low display compatibility required the dispatcher to embark on an active search strategy to locate the necessary information.

Implications for Design 4: This goal state of planning resource to task compatibility may be made more specific as it applies to the SCAT situation and may be re-phrased as "Where are the available SCAT officers nearest to the accident scene?". This suggests a display concept that integrates those manual searches performed in the current system in order to improve performance. Figure 2 illustrates a display concept that integrates the currently two manual steps. Current GIS technology allows the calculation of the shortest route or time between two sites, in this case, between the accident site and ambulance stations. This process in ARCInfo is called 'path optimisation' which takes into account path impedence as well. Path impedence is the resistance to travel which determines the speed at which a vehicle may travel through that path. The system having identified the nearest stations with SCAT officers then displays the required information with a higher degree of proximity-compatibility. In this manner, the information is portrayed in a manner that supports this specific decision objective.

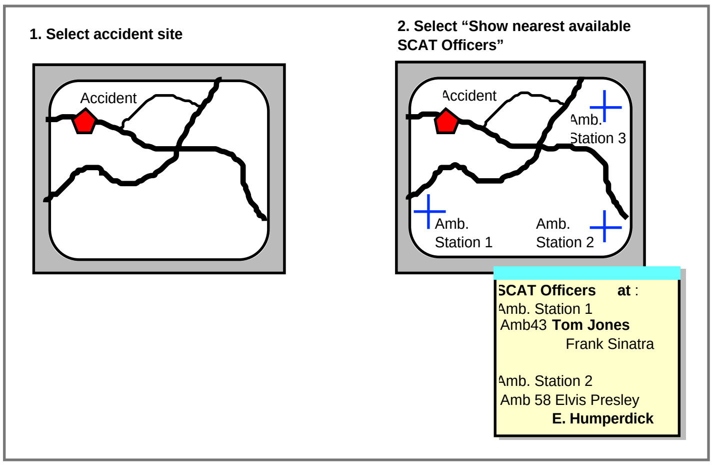

Figure 4 Integrating the "Show nearest available SCAT officer" display concept.

A more typical task in locating resources is that of locating the nearest available ambulance to an incident site. In deciding what is available, the dispatcher asks:

- what sort of ambulance is that?
- where is it ? (location: is it close enough to use?)
- what part of the job is it at? (based on job status information)
- what is it doing right now and will be required to do in the immediate future?

The dispatcher will then determine which vehicles were or would be available. To do this dispatchers have reported referring to three different places:

- the slips on the right-hand side of the table (vehicles at destination which indicate that they will soon be available)
- the dispatch status board (what's available)
- the staffing slip with the floor supervisor (for on-road supervisor information).

If the dispatcher has local knowledge of the area, he or she will then mentally superimpose the positions of available ambulances against a mental map of the area. They would mentally visualise which of these vehicles is closest. Otherwise they would refer to a map of the area and correlate reported positions of ambulances with the map.

It was observed that the search was somewhat constrained. The co-ordinator only looked at vehicles that were in the immediate area of the accident, rather than searching sequentially for all possible options. A display concept for this has already been reported in [13]

(b) Translating needs into resources to send. One of the key facets to planning is translating what has happened into the number of resources to send, as expressed by the following statements:

> To understand the nature of the accident in order to cover the amount of casualties.
>
> Need to know what had happened so that you know what resources are going to have to start moving into the area.

Receiving accurate information about the incident is very important to organising an appropriate response to the incident. However, in practice this is frequently not possible due to the agitated and sometimes incoherent state of callers. Instead, based on the uncertain information, dispatchers will organise a response of what they think to be an appropriate mix of resources, send them out as quickly as possible as indicated by the following statement:

> "… you dispatch … what you think will cover at the time that you need." 55

One major consideration that influences the number of ambulances to send is the concern with sending too many ambulances as indicated below:

> "You don't want to send too many vehicles and find that they are not wanted and I could be using them anyway." (396-8)

The reason for this is that vehicles which are not necessary for an accident become unavailable to other incidents to which they could have been sent. This represent a waste of limited resources.

Although these observations have significant implications for the design of call-taking screens, this issue was not pursued during the investigation. However, a call-taking screen for the St John's Ambulance dispatchers in New Zealand has been designed using a cognitive schema based approach [22].

(c) Planning ahead. Dispatchers were observed to be involved in two types of planning when co-ordinating ambulance dispatches. The first type of planning is done in real-time addressing the question of which ambulance is to be sent now to an incident. The second type of planning may be termed planning ahead, where the dispatcher attempts to predict what the future state of the ambulances will be and attempt to match that to a forecasted set of activities.

> Prepare resources by identifying what vehicles will be available in the next few minutes.
>
> Need to know what had happened so that you know what resources are going to have to start moving into the area.

For example, the dispatcher will identify which ambulances will become available in the next few minutes, determining whether they are in a position to assist in a given emergency, and if so, have them stand-by for further instructions.

Implications for Design 6: The display needs to support planning, i.e. *forward planning* (what routine jobs need to be performed in the near future) and *real-time planning*. As emergencies occur, the display needs to allow changes in the planned deployments. The co-ordinator must be able to re-assign tasks and re-assign new tasks.

(d) Minimising disruption to on-going activities. Closely associated with the goal to send an appropriate number of ambulances is the need to minimise disrupting on-going activities.

> To minimise disruption to on-going activities.
>
> "You don't want to send everything out of one area." (116) so that you will not be able "… to cover emergencies that are still going to happen … (117. 123)

Over-estimating the number of ambulances needed during periods where resources are stretched may require pulling ambulances off other less life-critical but necessary jobs, or delaying them, to the inconvenience of the patients.

(e) Planning to fill gaps in ambulance coverage. Often in major incidents, the number of ambulances needed is more than the number readily available in the area. This could be due to the size and extent of the incident, or it could be due to a level of on-going commitments from which ambulances cannot be drawn. As a result the ambulance coverage in the area could be badly depleted such that it may take a unacceptably long time for a vehicle from a neighbouring area to respond to an emergency. Such depletions are called 'gaps' or 'holes' in the coverage. To fill these gaps, ambulances from neighbouring areas are usually re-deployed to cover the gaps, stretching the coverage to a more acceptable level, as indicated below.

> To cover the holes made by bringing in your resources into the one area.

Implications for Design 7: Because ambulances or personnel from different stations may be responding to one incident, there may be a need to organise the status display according to the incident. All vehicles assigned to, say, the Mt Wilson incident will be displayed together in the display. Such a display organisation corresponds to the physical act of grouping all yellow slips and the tags of the ambulances assigned to an incident together in the same physical pile. The display would therefore support the task of managing incidents rather than vehicles.

In looking for reinforcements for an area, coordinators currently simply stand up in the room and visually scan the dispatch boards of each area to see what vehicles are available. They look at four pieces of information: (1) The tags pegged to the top of the dispatch board indicate what is available; (2) The number of tags that have been attached to white slips (non-emergency jobs, hence can be re-deployed if necessary); (3) The number of white or yellow slips placed at the right hand side of the desk (this position represents ambulances that have arrived or are arriving at the hospital and could be re-assigned a new job).; (4) Availability slips.

Implications for Design 8: This observation about the way a co-ordinator seeks for information suggests the following display requirements:

- Status displays need to portray what is available and not just what is in use.
- If a resource is in use it should also have some indication of case/patient severity. This plays a role in re-deployment decisions as not all emergency cases are equally life-threatening, though serious, e.g a broken hip vs a cardiac failure.
- The concept of availability should perhaps be further defined to include "Assigned, but re-deployable".

IV. Speedy response

Another goal state of the ambulance dispatch process is that of attaining a speedy response to emergency calls. The Co-ordination Centre has a requirement for a vehicle to be on the road within three minutes of receiving the emergency call. In all cases interviewed, all dispatchers were concerned with getting medical aid to the scene as soon as possible in order to start initial treatment, and to receive an initial report about the severity and extent of injuries at the accident.

V. Maintain history of developments

Although reported in only two of the five interviews, the need to maintain a history of what had happened cannot be overlooked. The main use of these histories is to assist legal investigators reconstruct events from job slips and other operational documents in order for investigators to determine what had happened and when it happened.

Conclusion

In this paper we have attempted to show how a cognitive task analysis was used to identify the goal states of a dynamic system, the cues used, the decision strategies invoked by the dispatchers, and to subsequently use the goal states to inform the design of display concepts. At the time of writing, work is continuing to develop these implications for design into practical and implementable display designs.

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