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DiCoT: a methodology for applying Distributed Cognition to the design of team working systems

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Abstract. Distributed Cognition is growing in popularity as a way of reasoning about group working and the design of artefacts within work systems. DiCoT (Distributed Cognition for Teamwork) is a methodology and representational system we are developing to support distributed cognition analysis of small team working. It draws on ideas from Contextual Design, but re-orients them towards the principles that are central to Distributed Cognition. When used to reason about possible changes to the design of a system, it also draws on Claims Analysis to reason about the likely effects of changes from a Distributed Cognition perspective. The approach has been developed and tested within a large, busy ambulance control centre. It supports reasoning about both existing system design and possible future designs.

1 Introduction

Most interactive systems do not consist of a single user with a single desktop computer. Yet most of the established methods for reasoning about the design and use of systems are still best suited for such single-user–single-device systems. Mobile, pervasive and distributed systems bring new sets of design challenges, and correspondingly new approaches are needed for reasoning about such systems. Distributed Cognition is an approach to reasoning about systems involving multiple people and artefacts who share a common purpose, which considers system changes over time in terms of the distribution of knowledge and goals around the system and how information gets transformed by the system. It has been widely touted as a method for reasoning about the design of distributed systems involving multiple people and interactive devices. Both Rogers and Scaife [12] and Wright, Fields and Harrison [13] have noted that despite the relevance of DC to HCI it has lacked visibility in the HCI community. However, to the best of our knowledge, there has been no concerted attempt to develop or test a methodology for applying the ideas of Distributed Cognition (DC) in a structured way for distributed work. In this paper, we present DiCoT (Distributed Cognition for Teamwork), a structured approach to analysing a work system in terms of the central ideas of Distributed Cognition as presented in the DC literature.

1.1 The approach

The approach taken was to start with a systematic study of the DC literature. From this literature, a set of core principles for DC were derived and classified according to primary theme. Five themes emerged; for the three main themes, appropriate representations were developed to support reasoning about that aspect of the distributed system. For this, we drew extensively on the early stages of Contextual Design [2]. These representations and the associated reasoning process form the core of DiCoT.

Two visits, each of half a day, were made to the case study organisation (London Ambulance Service, LAS); each involved both focused observation work and Contextual Inquiry interviews [2]. Data was gathered from call takers (who are seated in a group separately from the main control area), and from representatives of the three main control roles: telephone dispatchers, radio operators and allocators (who lead the teams and are responsible for planning, co-ordination and decision making). Data gathered during these visits was represented and analysed using DiCoT. The core DC principles were used to support reasoning about qualities of the design of the current system. In order to test the utility of DiCoT for reasoning about new designs, two re-designs of the system were proposed. DiCoT was applied to reasoning about these re-designs. Since these re-designs have not been implemented, it is not possible to validate the conclusions drawn, but this exercise has been a 'proof of concept' to show that the method can be applied to both existing and proposed designs.

Before presenting the detailed literature analysis and the case study, we briefly review related work on DC.

1.2 Background: Distributed Cognition

Various team-working contexts have been analysed in terms of DC. Hutchins [9] analysed the team working behaviours of, and the designs of the artefacts used by, the navigation team on a large naval vessel. Hutchins and others [7,8] have conducted similar analyses of team working and the design of systems in an aircraft cockpit. Fields, Wright, Marti and Palmonari [5] apply DC to an air traffic control (ATC) room to assess the representations and their distribution, manipulation and propagation through the ATC system. They recognise that a potential criticism of their work is the lack of method that takes them from analysis to design. Wright, Fields and Harrison [13] have tried to make DC more accessible to the HCI community by developing a Resources Model which clarifies how abstract resource structures can be coordinated in strategies to produce behaviour.

Wright *et al.* [13] intentionally address a single-user–single-device system to show how DC can be applied to traditional software design. However, they acknowledge that this is a potential limitation of their work, as a multi-agent system can involve a far richer array of cognitive subsystems and strategies.

Artman and Waern [1] analyse work in an emergency control room from a Distributed Cognition perspective. Their work contrasts with that reported here, in that they focus primarily on the dialogue between participants and how understanding is shared through the verbal channel, whereas the work reported here focuses much more on the artefacts in the environment and how their design and spatial arrangements support or hinder group working.

2. From the literature to DiCoT

Hutchins [9] presents DC as a view on how information is transformed and propagated around a system. The DC approach that is applied can be distinguished from other theoretical methods by its commitment to two related principles [6]:

1. The unit of analysis is expanded so that the "cognitive process is delimited by the functional relationships among the elements that participate in it, rather than by the spatial collocation of the elements".
2. The analysis looks for a range of mechanisms that can partake in the cognitive system rather than restricting itself to symbol manipulation and computation – e.g. the interplay between human memory, external representations and the manipulation of objects.

Hollan *et al.* [6, p.176] argue that many of the concepts and vocabulary familiar to classical information processing cognitive science can be retained, but that the unit of analysis needs to be expanded from the individual to the wider system. They suggest three ways in which cognition may be distributed:

1. "Cognitive processes may be distributed across the members of a social group";
2. "Cognitive processes may involve coordination between internal and external (material or environmental) structure" and
3. "Processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events."

This gives some indication of the sorts of observations and phenomena that a DC analysis might highlight; we have expanded on these by reference to the broader DC literature to present a set of principles of DC. The three themes that have been the focus of the work to date are: physical layout; information flow; and the design and use of artifacts. Two further themes – evolution over time and the role of social structures in coordinating activity –have not to date formed a focus for analysis, and are therefore omitted from the current account.

For each of the three primary themes, there are three components to DiCoT. The first is the set of principles that pertain to that theme; the second is a set of diagrammatic representations that illustrate structure and flow from the relevant perspective; the third is a set of tabular representations that present a summary of the system, details, further observations and issues that emerge, all from the viewpoint of the theme. This tabular representation focuses on narrative, and on highlighting features of the system in relation to the relevant principles.

2.1 Physical layout

The physical model describes those factors that influence the performance of the system, and of components of the system, at a physical level. This description is important from a distributed cognition perspective as those things that can be physically heard, seen and accessed by individuals have a direct impact on their cognitive space and hence will shape, empower and limit the calculations that individuals perform.

Thus, the first set of principles relate to the physical organisation of work – whether concerning the large-scale structures or the details.

Principle 1: Space and Cognition: Hollan *et al.* [6] discuss the role of space in supporting cognition. They present examples of the use of space such as supporting choice and problem solving. For example, in the work presented here, we found that ambulance controllers lay information out on their desks in ways that support their planning (e.g. by grouping the 'tickets' that correspond to future jobs by time).

Principle 2: Perceptual Principle: Norman [11, p.72] argues that spatial representations provide more support for cognition than non-spatial ones provided that there is a clear mapping between the spatial layout of the representation and that which it represents. An example from the ambulance control domain is that calls are displayed on the allocator's screen in order of priority.

Principle 3: Naturalness Principle: Similarly, Norman [11, p.72] argues that cognition is aided when the form of the representation matches the properties of what it represents; in these cases what is experienced is closer to the actual thing, so the necessary mental transformations to make use of the representation are reduced. This is referred to elsewhere as 'stimulus–response compatibility".

Principle 4: Subtle Bodily Supports: In interacting with the environment, an individual may use their body to support their cognitive processes; for example, pointing at a place in a book whilst responding to an interruption is part of the mechanism of remembering where we are (Hutchins, 1995a, p.236).

Principle 5: Situation Awareness: One of the key aspects of shared tasks is that people need to be kept informed of what is going on, what has happened and what is planned (Norman, 1995). The quality of this situation awareness can be influenced by how accessible the work of the team is. This can also be influenced by the proximity of the person, involving both observation and overhearing conversation. Situation awareness in ambulance control has been studied by Blandford and Wong [3].

Principle 6: Horizon of Observation: The horizon of observation is what can be seen or heard by a person [9, p.268]. For each person in an environment, this depends on their physical location, the activities they are close to, what they can see, and the manner in which activities take place. The horizon of observation of a person plays a large role in influencing their situation awareness.

Principle 7: Arrangement of Equipment: From a DC perspective, the physical layout of equipment affects access to information, and hence the possibilities for computation. This applies to the different levels of access to people, their conversations and their work as well as to physical representations and artefacts [9, p.197]. For example, in each team, the allocator and radio operator share access to certain items.

As we move from the principles towards modelling, there are a number of different levels which we might choose to model. We may take the environment of the individual, the team, the wider working unit or the organisation; the focus should be on logical units rather than necessarily physical spaces. For ambulance control, we chose to focus on the structure of the sector desks (i.e. the main unit in which a team works) and the layout of the room (the environment within which teams coordinate their activities).

In considering the effect of the physical layout of the system we focus on the component parts of the system and ask ourselves questions about the proximity of, and access to, devices and people: what can be seen in an individual's horizon of observation and what can be heard in an individual's zone of normal hearing? The answers to these questions affect the information processing ability of an individual and the information flow in the system.

For each level of description, we generate a summary then details, then add further observations and highlight issues that arise. Details cover two important aspects: support for communication and access to artefacts. We illustrate this briefly with extracts from the room level model.

The room level model describes the physical layout of the Central Ambulance Control room, both graphically (Figure 1) and in text. The description focuses on overall layout and the location of important shared artefacts such as call status boards. The summary and edited highlights from the additional detail sections are presented in Table 1.

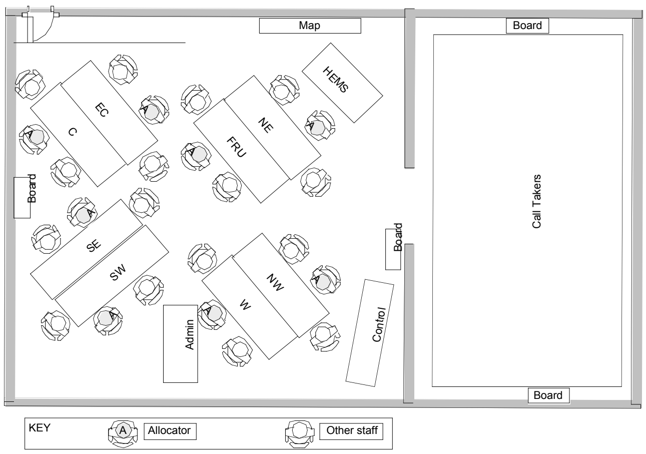

Fig. 1. Room layout (most sector desks are labeled with a region of the city; HEMS = helicopter control; FRU - fast responder units)

This description is produced iteratively. First, the diagram is checked iteratively to ensure that it includes all important artefacts and features. Second, the table is refined, pulling out issues relating the design of the system to the principles (identifying both positive and negative features). Space does not permit a full illustration of this process.

SUMMARY There are seven sector desks in the London Ambulance Service control room, each of which has the responsibility of allocating ambulances to incidents in an area of London. Although these sectors provide operational boundaries, where different allocators are responsible for certain areas, it is their collective responsibility to provide the best service for the whole of London; this entails cross boundary working. This is achieved by allocators communicating with each other across the room.
DETAILS *Communication (Access to Actors)* The sector desks are organised roughly geographically, so sectors that border each other are close by for communication (*Principle 5*). When an allocator identifies the ambulance closest to an incident, it may be an ambulance from a neighbouring sector. Permission to allocate ambulances from different sectors has to be obtained from that sector allocator. Hence, ease of communication between allocators is important for cross boundary working. Depending on where allocators are seated in the room, people will generally raise their voices to get their attention and communicate with them. If this is not possible then the telephone will be used. […] *Access to Artefacts* The most prominent shared artefacts, at room level, are the boards which indicate the status of incoming calls: how many call takers are free and the percentage of calls that have been answered within an allocated time period. These boards are located high on the wall so that they are accessible by everyone. This information gives an indication of how busy the call takers are, which indirectly indicates overall workload. […]
FURTHER NOTES • Call takers are situated in a different area from the sector desks. The floor to the call taker's area is at a lower level. This adds a further degree of distinction between the two and could help prevent sound travelling. • The control desk is raised to provide an overview of the room (*Principle 6*). […]
ISSUES • The allocators are not always within easy reach of each other. This may be important where an incident requires multiple crews from different sectors. • The display giving the status of the call takers' work load and performance does not directly impact on the allocators' work load.

Table 1. Physical model: Extracts from the room level description

2.2 Information flow

The physical structure partly, but not completely, determines how information flows and is transformed within a work setting. The second theme for analysis therefore focuses on information flow. More specifically, this turns the focus of the analysis to the communication between the participating members, what their roles are and the sequences of events, which define the mechanics of the system. We start by outlining the principles derived from the literature relating to how information flows and is transformed.

Principle 8: Information Movement: Information moves around the system. This can be achieved in a number of different ways which have different functional consequences for information processing. These ways differ in their representation and their physical realisation. Different mechanisms include: passing physical artefacts; text; graphical representation; verbal; facial expression; telephone; electronic mail; and alarms. Even inaction might communicate information [9].

Principle 9: Information Transformation: Information can be represented in different forms; transformations occur when the representation of information changes. This can happen through artefacts and communications between people. Appropriate representations support reasoning and problem solving [9]. One important transformation is **filtering**, in which information is gathered, sifted and structured. In ambulance control, filtering is a central activity of call takers, who solicit and structure information from callers for onward transmission to the relevant sector desk.

Principle 10: Information Hubs: Information hubs can be considered as a central focus where different information channels meet, and where different information sources are processed together – e.g. where decisions are made on various sources of information [3]. Busy information hubs can be accompanied by buffers that control the information to the hub, to keep it working effectively.

Principle 11: Buffering: As information propagates around a system, there may be times when the arrival of new information interferes with important ongoing activity. This can create conflict and increase the chances of an error occurring, either because the new information gets lost or distorted or because the interruption provokes a mistake within the ongoing activity [9, p.195]. Buffering allows the new information to be held up until an appropriate time, when it can be introduced. In the case of ambulance control, radio operators frequently buffer information for their sector allocators.

Principle 12: Communication Bandwidth: Face-to-face communications typically impart more information than those conducted by other means, including computer mediated communication, radio and telephone [9, p.232]. This richness needs to be recognised when technologies are redesigned.

Principle 13: Informal Communication: Informal communication can play an important functional role in the system, including the propagation of important information about the state of the system, and the transfer of knowledge through stories, which can have important consequences for learning how the system behaves [9].

Principle 14: Behavioural Trigger Factors: It is possible for a group of individuals to operate without an overall plan as each member only needs to know what to do in response to certain local factors. These can be dubbed 'trigger factors' because of their property of triggering behaviour [9].

Three separate viewpoints on information flow have been developed to capture different aspects of the way information is transferred around a system.

1. A high level view focuses on the overall input, transformation and output of the system.

2. An agent-based view focuses on the principal agents within the system and the flows between them. The properties of each of the main communication channels are identified. In this case study, we chose to focus on the human agents, and not to consider the interactions between a human and their computer systems: that was left for the artefact model. This decision was made because there is little computer-mediated communication in the current system design.
3. The third view is an adaptation of the second, focusing on how information is buffered, filtered and transformed within the system (referring specifically to the principles for information flow presented above).

For the second and third views, we have adopted the same structure as above, of presenting a summary, detail, further notes and issues. For illustrative purposes in this paper, we present just the diagrammatic representation of the enhanced information flow model (item 3 in the list above). This is shown in Figure 2, and expanded on in Table 2, which includes an outline of the key properties of each information channel and node.

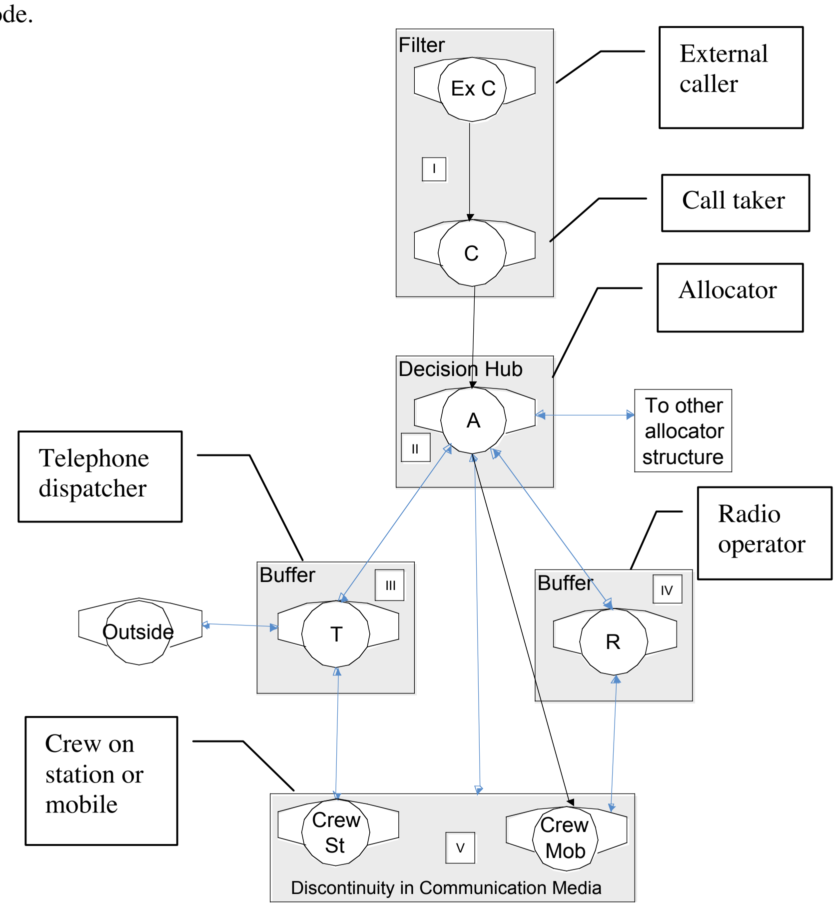

Fig. 2. Overview of information flow, focusing on buffers, hubs and filters.

Process	Summary
I Filtering of External Caller Information	Call takers receive calls from external callers who help in filtering out the required information so that the system can perform effectively. When appropriate, they will also negotiate times that hospital transfers need to be made with doctors, which has an impact on the management of resources in the rest of the system.
II Allocator at the Decision Hub	In focusing on the process of allocating ambulances to incidents, the allocator can be seen as the central person that makes the decision of what ambulance should go where and when.
III The Buffer of the Telephone Dispatcher	The telephone dispatcher supports the allocator by dealing with incoming telephone calls and contacting outside parties as required through the business of allocating. This provides an extended arm of communication for the allocator and protection against a potential barrage of incoming calls.
IV The Buffer of the Radio Operator	The radio operator supports the allocator by dealing with incoming radio communications from mobile crews and contacting them whilst away from the station. This provides an extended arm of communication for the allocator and protection against a potential barrage of incoming requests and queries.
V Discontinuity in Communication Media used by the Ambulance Crews	The ambulance crews have two mains forms of communication that they use to talk to the sector desk: they use the phone when they are at the station and away from their vehicle; and use the radio when in their vehicle. This discontinuity is amplified as the two communication channels are dealt with by different people at the LAS control room. In addition, the allocator can send information direct to the crew when mobile via their mobile data terminal.

Table 2. Description of the Main Flow Properties shown in Figure 2

The issues that emerge from this representation include the importance of buffers for helping the allocator perform effectively under high workload conditions, and the discontinuity in communication channels and media as crews move from being on station to being in their vehicles to being at scene. We discuss the second of these issues further below in proposing a small design change to the system.

2.3 Artefacts

As discussed above, from a DC perspective the environment that we inhabit plays a central role in cognition, bringing artefacts, representations, and environmental affordances centre stage in a cognitive analysis. Thus, a third important consideration within DC is how artefacts are designed to support cognition.

Principle 15: Mediating Artefacts: To support activities, people make use of ‘mediating artefacts’ [9, p.290]. Mediating artefacts include any artefacts that are brought into coordination in the completion of the task. In ambulance control, the ‘tickets’ that contain information about incidents are essential mediating artefacts, being passed around between team members and annotated to keep track of the state of the incident.

Principle 16: Creating Scaffolding: Hollan et al. [6, p.192] argue that people use their environment constantly by creating "external scaffolding to simplify our cognitive tasks". For example, we may create reminders of where we are in a task.

Principle 17: Representation – Goal Parity: One way in which external artefacts can aid cognition is by providing an explicit representation of the relationship between the current state and a goal state [9]. The closer the representation is to the cognitive need or goal of the user, the more powerful that representation will be. In the case of ambulance control, the allocator's goal is often to obtain a clear screen – one with no outstanding jobs.

Principle 18: Coordination of Resources: Resources are described as abstract information structures that can be internally and externally coordinated to aid action and cognition by Wright *et al.* (2000). The six resources that they describe in their Resources Model are: plans, goals, affordance, history, action-effect, and current state.

The artefact model considers the detailed design of individual artefacts that support the work of the team. In our case study, we focused attention on those artefacts and representations considered central to the performance of the system – i.e. the computer system, the paper call 'tickets and the call status board.

At an individual artefact level, we want to ask questions about how its design impacts on shaping, structuring and empowering cognition at either team or individual level. By building up a model of the artefact, and the system in which it operates, we aim to understand how it contributes to system performance. To this end we can use the Resources Model (Wright *et al.*, 2000) to help inform how resources are internally and externally represented in the system. The better the understanding we have of how information propagates around the current system, the better our chances of identifying design issues that should be attended to in any system redesign.

Diagrammatic representations of artefacts include both physical structures (e.g. the layout of a computer display) and how artefacts move around the systems (e.g. the ways ambulance control tickets are passed between team members and the significance of each transaction in terms of communication and coordination). These representations and related structures help identify strengths and limitations of the current artefact designs; for instance, as the ambulance service considers replacing paper tickets by a computer-based representation, the model helps identify the important roles and features of paper tickets that need to be preserved in any computer0based implementation of this functionality.

3. Reasoning about re-design

As a brief example of the use of DiCoT to reason about re-design, we consider changing the flow of communication between allocator and crews. As shown in Figure 2, and discussed above, there is a discontinuity in the ways Central Ambulance Control communicate with crews. We could propose changes in the information flow structure. More flexible communication channels could be added (e.g. personal radio or other mobile device) so that the crew could be contacted regardless of whether they are at a station or mobile. Also, the allocation of a crew at a station could be more automated; for example, an allocator could allocate a station, a data terminal would then alert all crews of the details at the station, and one crew would accept the call, which would then be forwarded to their vehicle. Both of these communication changes would reduce the need for a telephone dispatcher. An alert for station data terminals could even be incorporated on the new communication devices; e.g. it could operate something like a pager.

The merits and disadvantages of this modification can be considered by comparing a DC analysis of the new information flow with that of the old. Claims Analysis, described by Carroll and Rosson [4] as a form of "cognitive design rationale", has been chosen to represent this comparison. Such a design rationale is illustrated in Table 3. Since this analysis is being conducted from a DC perspective, considerations such as costs of set-up and maintenance of alternative communications devices have been omitted, but would clearly be important in a full consideration of design changes.

Design Feature	**Hypothesized Pros (+) or Cons (-) of the Feature**
Have a one-stop communication channel with crews	+ allows greater flexibility in contacting crew + could open potential for telephone dispatcher and radio operator to job share + can improve communications between crew and external party
Further automate allocating crews at a station	+ telephone dispatchers call to station is automated freeing them for other tasks + allocator can treat allocating a call to a station in much the same manner as a mobile vehicle - automation will need further equipment and the addition of activities performed by the crew - reducing verbal communication between LAS staff and crews might have negative social consequences

Table 3. Claims Analysis of more flexible communications to crews

This example is necessarily brief. It serves simply to illustrate one possible approach to using DiCoT to support reasoning about the design of systems that have not yet been implemented. The consideration of this design option has led to the identification of potential design issues that need to be considered if the system is to be reorganised, as summarised in Table 3. In practice, those design ideas that appear to have the best chance of improving the current system were not found to be big structural changes, but incremental modifications such as reviewing the communication channels between the sector desks and crews, and improving cross-boundary working through the computer system.

4. Discussion

The aim of this paper has been to develop a structured method of analysis for DC, iteratively developing an approach based on existing research and practice, using a case study to focus development. This case study approach ensured that we took account of practical limitations, complexities and constraints, and made it possible to constantly evaluate what was done well, what was not, and what needed to be included to make the method work practically.

The method took explicit account of most of the DC principles that had been identified in the literature, both in devising the representations to be developed (which also drew on the Contextual Design approach [2]), and in the subsequent analysis approach. The DC principles that have been downplayed in the approach are those that relate to the evolution of the design – a factor that is more central to Activity Theory [10] than DC – and to social factors. These would ideally be considered in an extended DC method, but were outside the scope of this study.

As well as developing a preliminary methodology for conducting a DC analysis, this study has also yielded useful insights into the design of an ambulance control system. Although the study has highlighted a few areas where the design of systems and work spaces could be improved, it has also highlighted why so many aspects of the current design work well. For example, it has shown why the positioning of the radio operator to the side of the allocator (so that many artefacts can be shared and good situation awareness maintained, and so that the radio operator can buffer information for the allocator at times of high workload) is effective.

The conception of how DC can be used as a design tool should be viewed as one possible approach to developing DC as a design tool rather than a complete account. The possibility of such a use for DC has been alluded to elsewhere but, to the best of our knowledge, has not previously been described. The use of such an approach in this context seems like a suitable way to proceed given that large complex systems (e.g. control rooms) cannot simply be physically built and tested. Claims analysis [4] has been used as an approach to aid design reasoning, and appears to be promising.

In the work reported here, we have aimed to address claims that DC lacks visibility within the HCI community, although it is relevant for analysis and design [13], and that DC cannot currently be used as an 'off the shelf' methodology [12]. By making the theory more accessible to understand and apply, it is hoped that practitioners and researchers will be in a better position to engage with it through practice, criticism and development.

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