

Distributed cognition: investigating collaboration in large and highly complex organisational systems

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ABSTRACT

Distributed cognition provides a framework for examining collaborative systems with the aim of supporting systems design. The approach gives the fieldworker a theoretical basis for structuring the analysis of data from their workplace studies within a problem-solving framework. Whilst the approach has been successfully applied in well constrained activity domains that involve closed systems, well structured problems and highly organised infrastructures, little is known about its application outside of these areas. In this paper, we explore how distributed cognition can be migrated to less highly constrained settings, and where difficulties lie in its application. To demonstrate this, we present and critically reflect on data from a field study with relatively poorly constrained features. The findings suggest that the use of distributed cognition in an augmented form will be useful in the analysis of a wide range of collaborative systems in poorly constrained and complex organisational settings.

KEYWORDS: organisational analysis, data collection, information processing, distributed cognition, collaboration, engineering design.

1. INTRODUCTION

Human-Computer Interaction (HCI), and more recently Computer-Supported Cooperative work (CSCW), has long been concerned with the study of work activities. The theories and methods developed for, and applied to, different workplace settings have been a mainstay of HCI and CSCW research and have contributed to our understandings of technology-mediated work. The emergence of theories which have moved the focus away from the single user to a wider consideration of interaction have brought new dimensions to HCI/CSCW's potential contribution. Such theories and associated methods of inquiry have provided new means of analysing and better understanding work practice, which can in turn inform the design of technologies to support and enhance work.

Distributed Cognition (DC) is one such approach, having been used as a means of analysing work settings both in cognitive science (see, for example, Hutchins, 1995a,b) and in systems analysis and design (see, for example, Flor and Hutchins, 1992; Rogers, 1993; Fields, *et al*, 1998). By attending to the informational content of activities, and examining them as information processing events, DC can support user-centred design, applying a cognitive engineering approach to the development and implementation of technology to mediate work.

Proponents of DC argue that the approach can be used to explore the performance of work by its participants and the co-ordination of that work through a variety of artefacts. It is unusual that it seeks to study people, social interaction and artefact use within a common framework. DC draws its theoretical and analytical foundation from cognitive science, which uses a mature vocabulary and set of exploratory techniques, augmenting these with techniques for primary data collection and ethnographic representation drawn from sociology and anthropology.

The analysis of work settings using distributed cognition focuses on representational transformations. These occur in systems as information is taken into them as an input and processed into an output that matches the system's goal. In practice, information about the settings is captured using ethnographically informed observational and interview based methods in field studies of the workplace. This has been described as 'cognitive ethnography' (Hollan, Hutchins and Kirsh, unpublished). Attention is concentrated on the actors/workers (who co-ordinate the representational transformations) and the media/artefacts in the environment (which encode the physical representations of work). The interaction between these elements is crucial in understanding how representational transformations are co-ordinated.

Whilst DC has been used successfully in understanding some working environments, its application has been limited to small, tightly focused and well-constrained (or 'closed') systems. As such, established studies of DC focus on well-defined teams of people using a specialised and limited tool set. Characteristics such as these are not shared in a vast range of work settings in other types of organisations.

The established focus of DC on a limited range of application areas suggests that it cannot be used to analyse other types of work, such as the more frequently encountered types of work in companies or organisations. However, this paper proposes that DC need not necessarily be so restricted in its application. In order to migrate DC to the study of less-constrained and less-ordered workplace settings, we will need to examine the current status of the approach and its characteristics. It is only through this, we suggest, that we can develop DC appropriately to study a broader range of settings outside the tightly specified and constrained activity systems previously examined.

It is important to understand the distinction between the characteristics of work systems that have been studied using DC, and the nature of DC as an analytical method. The focus - up to now - of applying DC to systems which are relatively simple, in terms of their structure, and which have a constrained set of problem solving activities, restricted resources and event durations, has meant that researchers can exert a high degree of 'pseudo-control' over many of the component parts of the setting and their use (see, for example the studies by Hutchins, 1995a,b). Exerting such control in many workplaces is likely to be problematic, since in the systems typically seen in other organisations, work unfolds over a period of time, the participants can co-opt a range of tools, and may introduce new people into the system to assist in resolving problems that are rarely well-understood. Deriving an analysis of such workplace activity directly from the methods used in existing studies of DC is unlikely to be an appropriate means of understanding them.

In the following sections we will examine the foundations and existing use of DC to highlight the major concerns over its use in large and highly complex organisational settings. Briefly reviewing the theoretical and methodological underpinnings of the DC framework will allow us to identify and discuss the areas of difference between the settings considered in existing studies and typical organisational systems. To demonstrate this, we draw on a field study, pulling out findings to highlight the application of DC in poorly constrained domains of work activity and to help us

propose suggestions for the development of DC and its evolution as an analytical method.

2. THE DISTRIBUTED COGNITIVE FRAMEWORK

The ideas behind, and terminology used in, DC reflect its roots in cognitive science. Classical cognitive science provides a conceptual framework with which to examine intelligence and problem solving, exploring how information is represented in the cognitive system, and how these representations are transformed, combined and propagated through the system in goal-oriented behaviour (Simon, 1981). These cognitive processes and representations are considered to be internal to the individual and held mentally.

In DC, a larger granularity of analysis is selected than that of the individual, to include the use of information artefacts in the cognitive process (see, *inter alia*, Hutchins and Klausen, 1991; Hutchins, 1995b; Norman, 1993). These include artefacts such as a pen and paper, which can be used as memory aids, as well as more complex artefacts that are integral to the computation, such as slide rules. As such, DC provides a strong and coherent framework with which to structure the analysis of workplace systems in terms of their informational content and problem solving activities. As well as incorporating artefacts in the cognitive analysis, DC also differs from classical cognitive science in its views of the cognitive process. DC suggests that the cognitive process can be described as being distributed over a number of people co-operating through social mechanisms, often referred to as 'socially distributed cognition' (Hutchins, 1995a; Hollan *et al*, unpublished).

The unit of analysis in DC may consist of any number of representations, embodied in people, computerised artefacts and non-technological artefacts (Rogers and Ellis, 1994). The DC framework provides a unique insight into how technology and the socially generated media of communication act upon and transform representations, and in doing so, perform computations, or information processing activity. The aim of DC is therefore to understand how intelligence is manifested *at the systems level* and not the individual cognitive level (Hutchins, 1995a).

The mix of people and artefacts in a given situation contribute to the *functional system* of activity, which includes all of the representation-carrying and representation-transforming entities involved in the problem solving activity. A distributed cognitive analysis examines the means by which the functional system is organised to perform problem solving. From a computational perspective, the functional system takes in inputs (representations), and transforms these representations by propagating them around the units of the system. A distributed cognitive analysis involves deriving the *external* symbol system (Newell and Simon, 1972) by capturing the elements of processing (representations and processes) that transform system inputs into outputs for particular tasks. In most cases, these distributed representations and processes are brought together by agents - people - and co-ordinated through social mechanisms.

Socially distributed cognition allows the analyst to describe group activity as a computation realised through the creation, transformation and propagation of representational states (Hutchins, 1995a; Simon, 1981). By bringing representations in the system into co-ordination with each other, information can be propagated through the larger cognitive system, being continually modified and processed by a number of individuals and artefacts, until the desired result is reached. However, whilst processing of the information available to the group is analogous to an individual's cognitive capabilities, the architecture of this activity differs significantly. How these socially embodied activities are organised with respect to one another is known as the division of labour.

Understanding how this division of labour operates is central to our understanding of work organisation and working practices (Clegg, 1994). Distributing work across a group of agents must involve the organisation of that group to co-ordinate activity. To solve a problem collaboratively, the division of labour must operate so that work is broken into parts so that individuals can bring their expertise to bear on sub-tasks, before re-incorporating the sub-task with the global task. However, within the distributed cognitive system, problem solving expertise lies not only in the knowledge and skills of the individuals, but in the organisation of those individuals. This organisation may be determined through the context of their work environment and the configuration of the tools that they use (Hutchins and Klausen, 1991). How such strategies arise is a subject of intense interest in CSCW (Heath and Luff, 1991; Lave, 1988; Rogers, 1993; Suchman, 1987).

The extent to which the division of labour is clear-cut and explicit in the work activity will influence the extent to which we can easily develop an accurate view of the distributed cognitive system. Where the activities, actors and information artefacts in a workplace system are constrained and work roles are explicit, the application of DC to analyse the functional system is likely to be relatively straightforward. This is likely to be particularly the case if the information within the system is represented explicitly and can be tracked through its transformations in the system.

A central feature of a distributed cognitive analysis is that it examines representational states, information flows, and the co-ordination and breakdowns that compose work, leading to a better understanding of the ways in which collaboration is co-ordinated and work undertaken. Data on which the analysis is founded is gathered through field-based observational methods, focusing on the identification of information-representation transitions (Flor and Hutchins, 1992) in the functional system that result in co-ordination and problem solving activities.

Data collection within the analytic framework of DC must allow the identification of the representations and processes in the goal directed behaviour. The analyst (or cognitive ethnographer) needs to show how these elements are used as resources in information processing by demonstrating how this is mediated through *action*. The DC perspective influences data collection by placing emphasis on the role of the artefacts carrying information representations, and on the collaboration around these artefacts. Observations therefore centre on the artefacts that are used or created, how they are used, who they are used by, how changes are made to them, and how the organisation structures access to these artefacts.

These features can be captured through the use of ethnographic techniques, which can be used to gather naturalistic data about activity within workplace settings. At its core, ethnographic analysis provides a means of exploring *how* work is organised (Hughes *et al.*, 1992; see also Anderson, 1994; Hammersley and Atkinson, 1995; and Hughes *et al.*, 1992 for overviews). DC can be used as an analytic framework to structure the ethnographic data, allowing the analyst to focus on the salient points relating to the cognitive (information processing) characteristics of the functional system. In order to do this, data about the task, the tools used, and the organisational context of their activity need to be tracked, following the information input and output pathways of the functional system. The analysis of the data involves mapping out the information flows through the organisational structure, identifying the sources and sinks of this information, the tools used to manipulate and transmit it, and the 'chains of command' initiating activities.

Whilst DC has a number of highly useful features in representing the information processing component of collaborative work, we recognise that, as with any description of activity, potentially valuable information about work can be lost. This

can have benefits, when information not relevant to the problem is filtered out, but it also means that important information about the setting can be lost. One example of this is motivation - DC analyses cannot provide a means of examining motivational factors in work relevant to the performance of the task. The problem solving systems described in DC are 'impersonal' (i.e. systems are described in terms of their external resources), and whether or not the work is tedious or poorly rewarded, this is not considered. In analysis, all agents are expected to perform work in the same way, whatever their personal concerns. In answer to this, the DC analysis is engaged in *an* (and not *the* definitive) examination of work, as *performed* (i.e. enacted, or situated knowledge [Lave, 1988]), to give a better understanding of *real-world* (and not idealised) activities.

A general criticism that has been levelled at distributed cognition is that problem solving is not an adequate description of much co-operative work. This is of course true, but it is of relevance to particular instances of co-operative work, particularly when work is collaborative, and when what Hutchins (1995a) described as 'pipelining' occurs: the partially completed results of one person's actions are passed on to another, who will then act on this, passing it on again. The DC approach therefore allows us to examine aspects of group activity - under particular circumstances - as information processing events.

In principle, the analytical framework offered by DC would clearly be of value in the analysis of highly complex organisational work systems. This would occur both in terms of developing improved understanding of the systems, and as an input into the re-design of work systems through technology and organisational processes. However, the nature of many workplace activities is such that the functional system within which they are situated is not fully specifiable or easily captured by the cognitive ethnographer using a standard DC approach. This appears to have so far limited the potential for applying DC as an analytical method in such contexts.

3. A COMPARISON OF STUDY SETTINGS

If we are to assess the value of DC in analysing highly complex organisational settings, it will be helpful to provide a comparison of the key constituent dimensions of such settings against those of the settings which are characteristic of published studies of DC (see table 1. for a summary). We will refer specifically to the 'navigation' systems considered by Hutchins, 1995a as they are representative of the systems to which DC has been 'applied'. The comparison will help provide a framework of issues in considering the application of DC across settings. The comparison is illustrative only, and is not meant to suggest that all contexts share all of these characteristics. Rather, these issues are intended to highlight areas where there are likely to be contextual differences which impact on our ability to employ DC effectively. We can then focus on these areas, presenting appropriate examples¹ to assess the broader usefulness of DC.

¹ Taken from an illustrative field study of work in the construction industry (Perry, 1998)

Key Dimensions	Navigation System	Organisational Systems
<i>Access to resources</i>	Closed systems where the types of actors and information artefacts are restricted to a predetermined set	Open systems, where the actors and information artefacts are more fluid, less easy to pre-specify, and may change over time.
<i>Problem structure</i>	Well-structured, identifiable and expected problems which are likely to be recurrent.	A tendency toward ill-structured problems which have a much higher degree of uniqueness.
<i>Organisational structure</i>	Organisation has pre-specified modes of operation, characteristic of tightly constrained and managed organisations with rigid modes of operation. Division of labour is well understood and 'standard operating procedures' underpin normal work.	Organisation's operation is only partially pre-determined, with established work processes augmented by ad-hoc approaches which may become institutionalised over time by the organisation as appropriate. Division of labour is less formally defined and enforced.
<i>Cycle duration</i>	Relatively short cycle for problem solving, tied tightly to the type of task being undertaken	Problem-solving cycle tends to be much more variable, with different classes of problem in the same workplace system taking place over widely different time scales
<i>Problem dynamics</i>	A relatively stable and unchanging/static process for problem solving.	More pragmatic and less-constrained problem solving.

Table 1: A comparison of key dimensions in workplace settings

Access to resources

The main difference between navigation and organisational systems can be described in terms of the distinction between an open and a closed system. In navigation, the system is closed: no external agents are permitted to involve themselves in the system, and the process has a fixed and restricted set of resources. In most other forms of organisation, the system is open, and its participants can call on a larger set of resources, which may not be initially specified. In general, there is also scope for more creative use of the resources that are available - that is, the working practices may be less rigidly defined and enforced.

Problem structure

The problems that the two types of system have to solve are also structured in different ways. In navigation the problem is 'well-structured' prior to its solution; the task is repetitive and actors are well practised in performing the task. In other organisational systems the problem is more usually 'ill-structured' and only becomes well-structured through collaboration between actors: the participants learn about the problem during problem solving, because many of the techniques they use are specific to the problem in hand.

Organisational structure

The methods that are used to organise the co-ordination of activity differ between navigational practice and in other organisational systems. In navigation, the communication pathways are (necessarily) well-specified and constrained to pre-specified modes of operation. These are enforced by naval regulations, which prescribe the division of labour on particular tasks. However, in other organisational systems, not all of the communication pathways are well-specified prior to problem solving, and their organisation is only partially constrained by pre-determined modes of operation.

There are few absolute organisational structures, and the artefacts, communication pathways and participants available are more likely to change over time. Some processes may be formally specified, but many are generated in an *ad hoc* fashion. In addition, the constraints on work may change as legislation and professional standards are modified. Whilst this may also be true for navigational systems, changes are much less frequent.

Cycle duration

The duration of the activity cycle differs substantially between the two areas. In navigation, the 'fix cycle' is of short duration (a matter of minutes or seconds). These fix cycles are 'snapshots' in time, and each involves taking a bearing of the vessel's present location. However, other organisational systems, the work process can occur over much longer time-spans. In one sense, this reflects the difference in the work being done, with the task focus of navigational systems being much more apparent and where the tasks are self-contained and very much time-critical.

Problem solving dynamics

The changing nature of the problems faced by the navigators and by actors in other organisational systems differs substantially, and this has implications for the way that strategies for problem solving develop and enter the culture of the workplace. Navigation by triangulation is an unchanging process, developed over centuries of practice². The procedures can remain unchanged over multiple fix cycles, and although each cycle may be of short duration in itself, they are highly repetitive. In organisational systems, the duration of the project determines the organisation of the functional system; over time procedures evolve, adapt and develop. During this time, new behaviours and processes may develop as problems arise, so there may be no effective precedents to behaviour. Most procedures are defined at an abstract level and can be changed as circumstances demand, and it may be left to the interpretation of individuals to decide on what actions to take. Whilst we recognise that navigational work is not always routine, this is more exaggerated in organisational systems.

These brief descriptions suggest that work performed by navigational and other organisational systems is very different, in terms of goals, technical resources and contexts of use. However, they may both be seen as information processing systems with a similar high level structure and it is at this level that a common approach like DC *can* be applied. Nevertheless, because navigation and other organisational systems differ in these significant ways, it is likely that the methods used to examine them will also have to differ. This suggests that we cannot draw directly from Hutchins' studies of navigation, which are representative of the systems so far normally considered by DC, and apply these directly to the analysis of other workplaces. Rather, we need to consider the differences more closely, undertaking and drawing on new studies of organisational work to help us evolve effective methods for distributed cognitive analysis into these contexts.

4. DISTRIBUTED COGNITION IN ORGANISATIONAL ANALYSIS

This section shows how DC can be applied to the study of a wider range of settings than has previously been examined. Through examples it demonstrates:

² The work of positional location described by Hutchins (1995a) has radically changed with the introduction of the Global Positioning System (GPS). Here, the problem of location has itself been transformed: satellite information rather than visual information is used, and the configuration of the functional system in navigation is therefore also likely to change.

- i. the differences between the traditional domain of study for DC and the less constrained, highly complex organisational settings discussed in section 3; and
- ii. an approach to gathering data that allows us to undertake an analysis of aspects of work within these highly complex settings.

The rest of this section introduces a field study from which several examples are drawn. These examples are intended to illustrate the two points above, rather than demonstrating a particular point about the engineering design process that the data was taken from. This fieldwork provides a basis from which we argue for the development of a novel and augmented approach to the use of DC that is applicable to the analysis of a wider range of workplace settings.

4.1 Background to the Study Setting

The field study involved an examination of design and construction on a large road building project. Fieldwork covered the participation of three spatially distributed divisions working for a construction company. To build the permanent road structures (the ‘permanent works’), the construction company had to design supporting structures known as ‘temporary works’. The temporary works comprised of non-permanent items, such as scaffolding, concrete moulds, supply roads, and so on. These temporary works were derived from the designs of the permanent works, but their designers had to take into account the site conditions (slope, weather, soil condition, and existing structures) and the available resources (money, time, materials, equipment and labour) that were not accounted for in the permanent works designs.

A large number of people were involved in the process that formed the functional system, including a construction team, made up of a team leader, seven engineers (one senior, three site, and three graduate engineers), two foremen (work supervisors), two gangers (junior work supervisors), and general labour (fluctuating at around 40). The team operated on the site, but were supported off-site in specifying the design of the temporary works by a design co-ordinator who worked at another location on the site. The design co-ordinator worked closely with a design engineer (located several miles from the site) to develop the team’s requirements into a temporary works design solution. Several other individuals and groups external to the organisation were closely involved in the process. These included a ‘resident engineer’, who checked that the road was being built according to contractual standards, a railway operating organisation, over whose tracks a road bridge was being built, and an environmental agency, responsible for pollution monitoring.

The high level goal of the functional system was to construct the road, according to the permanent works designs and contractual details (quality and time), with commercial constraints (on cost) without disrupting railway services or causing watercourse pollution.

A huge number of representations operating in the system were identified. These were held in artefacts, which formed the tangible media representing design information, and within the minds of individuals (which were not directly observable). The physical media included drawings, paper and pencil sketches, letters, post-it™ notes, schedules, letters, method statements, risk analyses, works records (a diary of site instructions, records and requests for information), and other paper based forms that had to be completed in the course of work. All of these artefacts bore representations that could be communicated between the collaborating actors involved.

The design processes were partially prescribed in the handbooks and manuals that determined relationships between people, and in the organisational structures they inhabited. These specified where the responsibilities for tasks lay and determined the

roles that the individual people had to fulfil. Whilst these were generally followed, particularly the safety-related rules, they were used more as organising principles, followed when appropriate, but worked around when other methods might be more appropriate in the circumstances. Clearly, this can be compared to the work of Suchman (1987) which shows how rules are used as resources for action, but not deterministically as generators of those actions. Context played a major role in the interpretation of these materials, as we shall see in later sections.

Structures in the environment at the site and office also played a role in determining the processes that would be applied to particular problems. These determined the configurations of representations and processes that *could* be applied in the design problem. For example, on the site, large distances made the location of people difficult, and communications were complicated accordingly. In the office, however, people were co-located, and had a range of media at their disposal with which to communicate.

The transformational activity performed by the functional system involved taking inputs into the functional system, transforming them into representations that could be applied in the problem solving process, and re-representing them until they matched the desired goals. Problem solving therefore involved co-ordination of the representations by matching them to the appropriate processes. However, the different resources available in particular circumstances, and the different ways in which individuals could resolve the problem-solving situation, meant that problem resolution could be achieved in a variety of ways. Hutchins (1995a) recognises this feature of work, and describes how 'local functional systems' are built up around - and exploit - the particularities of individual problem situations.

4.2 Illustrative Examples from Fieldwork

Having established the broad setting of the field study, we can now look at it in relation to parts i. and ii., exploring the differences between traditional studies of DC and the construction setting, as well as the approaches used to gather data in undertaking an analysis of aspects of construction work within the DC framework. These examples from the fieldwork illustrate the five key dimensions described earlier. These dimensions are not intended to be completely distinct and there are interdependencies between them. What we are attempting to do here is to clearly demonstrate, through examples, the difference between functional systems in design and construction, and the kinds of functional system previously examined in DC analyses. This will provide us with the necessary fuel with which we argue for a different approach to the application of DC in these settings.

Access to resources

The key resources in design and construction (actors and artefacts) are rarely pre-determined before the problem solving activity is initiated. The fieldwork illustrates how the problem solving activity changed as additional actors and artefacts become available. When designs or requests for information arrived at the site, there were a variety of different ways in which problem solving could be performed. Hutchins (1995a) recognises this 'availability of data' as a key controlling factor in how a functional unit can organise its computational and social structure. Additional information can lead to new social arrangements, which in turn lead to new computational structures (ibid. p.342).

The construction team's office was an important resource for their work, in its layout and use. It had an 'open plan' layout, and the engineers and quantity surveyors were able to see who else was present. It allowed them to speak to each other without moving from their desks, to overhear other people on the telephone or when speaking to each other, and to see the information laid out on each others desks. There was a

relaxed atmosphere to interactions, and when members of the team were not doing any work, they would engage in social conversations, or join conversations if something interested them. These conversations almost always turned to work.

Whilst the construction team were centred in this office, individuals spent a large amount of their time on-site. However, the distributed nature of the construction site made contacting individuals difficult. When people were not present to talk to directly, other media were used to communicate, either through the use of the radio link, through placing written notes, sketches, method statements or risk assessments on people's desks, or jotting notes onto a whiteboard. Messages were also left with people who were in the office for when that person came back. A photograph of the office space, its contents and layout is shown in figure 1.



Figure 1. Photograph of construction team office.

As can be observed, the workplace was covered with paper and other sources of information. Paper covered almost every surface, often several layers deep, and frequently referred to material was pinned up on the walls. When information was required from a person who was not physically present, this 'desk litter' could provide clues to their location, in the forms of the drawings and other representations on the desk, as well as the task that they were currently engaged in. Other artefacts also provided information about the whereabouts of people: if a person's Wellington boots and hard hat were missing, they were probably out on site; if someone had a pair of muddy boots under their desk, it meant that they had been on the site and could be asked about the current work situation. Depending on the weather, it was even possible to see how long ago a person had been out on the site, for example from the wet or dried mud on boots, which could be useful if one of the team was trying to locate another individual out on the site. Equipment such as the geodimeter was also useful in this way - if it was missing from the office, then a graduate engineer would be out on site (in a known location) and could be asked to run a favour by the more senior engineers over the radio. Even the window was used to see whether people's vehicles were in the car park outside the office: if this was the case, then that person was highly likely to be somewhere on the site.

One of the ways that information was passed around the team was through their asking questions; this might be a direct question to a particular person, or a general question, shouted out so that anyone in the room might answer. These questions usually were simple, and once the answer was given, the conversation was terminated. Spoken communication was conducted from the desks, allowing all of the participants in the room to be aware of developments, or allowing them to contribute to the discussion. When the senior or site engineers wanted to speak to the graduate engineers, they would stand up and chat over the tops of the partitions, providing a visual and auditory focus of attention in the room. This allowed people to work whilst keeping an ear to the conversation, keeping abreast of developments, to ask questions, and to add to the discussion. An example of this is noted in box 1:

Senior engineer: <goes over to graduate engineer at his desk> 'Have you got the delivery tickets for fifty two fifty six?' [the term relates to a particular set of substructure pile reference numbers].

Graduate Engineer: <mumbles. Begins to search through a file on his desk>.

Quantity surveyor: <sitting on desk opposite graduate engineer, and overhears conversation> 'I've got copies. I think I've got the ones you're looking for'.

Box 1: peripheral awareness in the site office.

In addition to these 'open' conversations, telephone conversations were carried out in loud voices; this was partly because the level of ambient noise in the room could be fairly high, but also because it allowed the others in the room to overhear (one side of) the conversation. One of the site engineers in particular would deliberately raise his voice whenever he was speaking about topics that he perceived to be particularly pertinent to the others. Occasionally he even stood up and waved his arms around to gain attention, or pointed to artefacts that were relevant to the discussion so that the others in the room might better understand the topic of conversation.

Within the literature of workplace studies and CSCW, these observations are relatively commonplace (Heath and Luff, 1991; Heath, Jirotko, Luff and Hindmarsh, 1993; Murray, 1993). However, within the DC framework, the analyst must draw from their observations how particular representations are propagated and transformed. Here, in the example above, the range of representations to select from is enormous, and they can be used in a variety of ways to achieve the same goal. In the event of a similar situation arising, it is unlikely that the same resources will be available in the same configurations as before, and used in the same way. This differs significantly from the examples of distributed cognition documented in aircraft and navigational settings, where stable behavioural patterns (Hutchins calls these 'computational sequences') tend to recur.

The consequences of this resource-flexibility for the use of DC outside relatively stable and informationally restricted work settings are that it is harder to build generalisations or models about work. In these situations, ethnographic descriptions of work are likely to represent 'one-off' solutions, generated by members who generate and maintain a computational structure that utilises only a subset of the potential resources available. Such descriptions will therefore be useful to illustrate how and which resources are used, but they cannot be seen as anything more than exemplars, or instances of problem solving - at another time, work is likely to be performed in a different way.

Problem structure

The examples below demonstrate the nature of the problem structure faced in the construction setting. The design/problem space is poorly understood prior to the initiation of the problem solving activity (i.e. they are ill-structured [Simon, 1973]), and a component of the problem solving activity is to understand exactly what the

problem is as well as to resolve it. This differs significantly from previous studies of DC in navigation and cockpit activity, in which regularised and well-structured problems are encountered. The examples given below demonstrate the structure of the problem faced by the designers. The section begins with a description of the global design situation and goes on to show how within this, ongoing problems were identified and transformed from ill-structured problems to well-structured problems:

In order to begin the steel work, concrete pours and other general work that made up construction, resources had to be put to work, in terms of labour, plant and materials. Much of construction work was demand led, and work could only occur when the site had been prepared: materials or other resources might have to be ordered or cancelled at the last minute because the site was prepared for the work earlier or later than expected. The use of different construction methods or materials (which might be used because of product non-availability, or particularities of the situation) in the permanent structures could change the project's specifications, and such changes would need to be checked with the RE. Changes to the materials used in temporary works structures also meant that these designs had to be checked by the senior team engineer or off-site, by the temporary works designer.

Information relating to the state of the site was collected from the different groups of workers on the site, each using their different skills and experience to determine discrepancies with the original designs. Small problems relating to the construction materials would usually be noticed by the tradesmen, who would pass this information to the gangers, where it would precipitate upwards through the team hierarchy to the graduate engineers. These in turn would either record the problem in the 'works record' (this functioned as the site diary - the official record of activities on the site), or as in most cases, they would mention the problem to the site engineers who could determine an appropriate course of action.

Structural problems on-site would be determined by the engineers, based on their patrols around the site (known as 'site visits') where they would check how the activities that they had been assigned to manage (by the senior engineer) were progressing. These site visits were an opportunity for the engineers to engage in *ad hoc* encounters with the workers on the site, which provided a source of information on developing problems. An example of a site visit is given below in box 2 (taken from fieldnotes):

In one site visit, a site engineer was taking a crane hire representative around the site, to discover what sort of crane they would require to place some beams onto the bridge underside - an awkward situation to reach.

Standing under the bridge, the site engineer and the crane representative were joined by a foreman, and as they discussed the section, they pointed up at the bridge area that they were referring to. They deliberated over possible methods of access to the bridge and scaffolding, and other features that would have to be removed or reached over by the crane.

Whilst involved in this discussion, the assistant section RE (the RE's representative on site) saw them and came over. They became embroiled in an (amicable) argument over the method used in a concrete pour on a section of the bridge adjacent to the area that they were standing on. It appeared that the Project Engineer had not specified in the drawings *how* the concrete was to be poured; the team's engineers had decided on a method that was not approved by the RE (although he could not legally enforce this due to the oversight). No answer was reached, but they agreed to continue the discussion at a more convenient time.

Box 2: *ad hoc* encounter on a site visit.

The example in box 2 clearly demonstrates how little was fixed in the detailed design process until much of the design and construction was already underway, first in the means of accessing the bridge, and then in determining a means of pouring the concrete. In this situation, no resolution was achieved, but the problem was noted and discussed later. In a second example below, we show how physical representations were used to structure the design space and to help resolve the problem:

In official project procedures, the team's senior engineer should formally present the initial 'design brief' (a temporary works design specification) to the design co-ordinator before a temporary works design could be generated. In practice, this design brief was often little more than a few ideas sketched or jotted onto a scrap sheet of paper. This occurred because the senior engineer had too little time to perform the task, and often had very little understanding of what information the design engineer might require in the problem specification. Through discussions with the design co-ordinator, a detailed specification would be generated, containing information about the site conditions, the materials, labour and other resources available to construct the temporary works structure. The construction team's senior engineer and the design co-ordinator would then sit down together and pore over the permanent works drawings, the initial temporary works design brief and several sheets of blank paper. As they discussed the problem, both tended to make sketches, and they often elaborated on old sketches. This can be seen in the next example in box 3:

Senior engineer (SE): 'If you look here, there's a barrel run there' <points at sketch generated in the meeting of a section view through a design structure>

Design co-ordinator: 'Yes I see'.

SE: 'So if we dig here...' <he holds one hand to the sketch and runs a finger on the other hand along a permanent works drawing (plan view) beside the sketch, indicating a line of reference>

Design co-ordinator: 'No you can't do that because of drainage problems...' <pauses> '...No, no, I see now'.

SE: 'So if we cap these piles here...' <indicates several points on the sketch>

Design co-ordinator: 'Yeah. OK. Lets do that'.

Box 3: use of multiple media in collaborative problem framing.

This second example involving the transformation and combination of information on two representations again shows how little was understood by the actors about the problem structure before they commenced the design process. The problem itself (generating an effective way to provide structural support) arises out of the comparison of artefacts (sketch and drawing). Having recognised the problem, the two (not shown in the example) went on to generate a solution.

The structure of the problem in the work of construction is not fully specified, and the problem solvers must endeavour to clarify what they need to do to achieve their goal (in the case of the last example, to provide an appropriate form of structural support). The typical cockpit and navigational examples shown do not involve this form of behaviour: the problem solvers already have a known problem and a well-practiced set of procedures with which to attempt a solution. The importance of this difference in problem solving for DC in complex settings is that the problem space is constantly changing over the time period - and repetition of activities is infrequent.

Where part of the problem solving behaviour involves the functional system in self-organising itself, much of what is observed is not directly problem-centred but involves re-organising the functional systems' internal processes around the dynamics of the problem situation. In many ways, this is itself a problem solving activity, but it is very

different in nature to a functional system that is already self-organised to solve a well-understood problem (such as navigation). Whilst self-organisation is recognised and discussed by Hutchins as a feature of activity within functional systems in navigation, we have observed far more ongoing self-organisation in highly complex settings. A crucial component of self-organisation is the awareness of the participants about the state of the local functional system. This state awareness means that the participants are able to organise themselves appropriately to the problem situation, because they do not know what to expect from the problem itself. The analysis therefore needs to clearly show how the participants in the functional system manage to achieve situation awareness. Situation awareness is not normally assumed to be a part of problem solving in DC (because it is not associated with representation transforming activity) and as such has been relatively ignored. We argue here, that in DC studies of complex settings, situation awareness *must* be considered as a core feature of activity, even when it is not directly associated with a particular problem-solving event.

Organisational structure

In this section we show examples of how the components of the functional system were organised in the construction project. In the terms used by Hutchins (1995a), there were a number of documents that determined a 'standard operating procedure' (or SOP) including manuals and handbooks. However, their application was not as rigidly enforced as those of navigational or aircraft cockpit systems, for a range of reasons (in navigational SOPs, these may control time criticality, safety, number of participants, and personal accountability). The organisational structure inherent in the SOP provides a basic structure for construction work, but it allows flexible interpretation by the actors involved. The example in box 4 shows an instance of how materials were ordered by the construction team and the resourceful way in which they managed to accomplish this (from fieldwork):

<Scene: A site engineer is on the telephone, speaking to a remote person and discussing a concrete pour. Only this part of the telephone conversation could be monitored by the fieldworker>

Site engineer: <stands up and speaks loudly into telephone> 'So, what I'm asking is: should we put concrete into the tower?' <raises his head and looks at the senior engineer with raised eyebrows>

Senior engineer: 'Yes'.

<Site engineer, completes the telephone call, then lifts a radio to speak to a foreman to give the go ahead. A graduate engineer overhears this:>

Graduate engineer: <orients towards senior engineer> 'Do you have any spare...<pause>...can I have three cubic metres?'

Senior engineer: <Pauses. Looks at ceiling. Pushes tongue into side of mouth. Pauses. Looks at graduate engineer> 'OK. Yeah.'

<Site engineer overhears this and radios through to the foreman to arrange it>.

Box 4: an opportunity for the flexible accomplishment of work.

In this observation, the potential to overhear telephone conversations (because of the open plan office space) was used by the site engineer as a means of asking the senior engineer if he could go ahead with construction. This was not pre-planned, but arose from a request for information arising from a distant third party. A graduate engineer, in turn, overheard this, and made a request for materials, which was arranged by the site engineer. None of this was prepared in advance. Tasks were fluidly discussed and finalised as the participants were made aware of on-going activities around them, which they used to initiate and direct their own work.

This situation was able to take place because of the open plan structure of the office space, but also because the participants knew that they did not have to order their materials through the specified SOP, by ordering each load of concrete through a formal order. It was possible to avoid duplication of a materials order (and the accompanying bureaucracy and wasted time) by taking advantage of the ongoing activities around them.

A second example shows how the organisational structure acted as a resource for problem solving, whilst the mechanisms used in resolving the problem were socially mediated and negotiated between people:

In the construction project, tasks were allocated to people through a number of mechanisms, dependant on hierarchical structures of seniority and the contextually dependent features of the setting. Whilst allowing a degree of autonomous freedom in behaviour, the participants understood their responsibilities and the roles that they were expected to perform. The example in box 5 illustrates how knowledge distribution occurred through a variety of actors and media. A graduate engineer was asked to check on the particular characteristics of a concrete mould (known as “shuttering”) by the clerk of works (from field notes):

According to the [company regulations], queries raised by the [resident engineer] or their staff should involve recording the problem, finding the answer, and filling out a ‘works record’, which would be sent to the site office, placed on file, and a copy sent on to the RE.

Accordingly, the graduate engineer filled out a works record form with the problem request and sketched a diagram of the concrete shuttering and the setting it was placed in. He telephoned <someone> off-site, and discovered that the information he needed about using the shuttering was in an advertising/promotional leaflet sent out by the shuttering company, and was held [on file] in the team office.

The information was lying on one of the foremen’s desks, who had been looking through it with an eye to ordering more materials. The engineer read off the technical details from a table on the leaflet and added this information to the form.

The engineer then posted the works record to the site office for inclusion into the [file] for circulation. As a works record, no accompanying information was required because the form of the document meant that it would always be processed in the same way. Due to the slow speed of the internal postal service, the engineer later went back on site, located the clerk of works [employed by the resident engineer] and reported his findings personally.

Box 5: knowledge distribution over multiple media.

The example demonstrates how the members of the local functional system (in this case, the graduate engineer, unknown telephone informer, foreman, clerk of works, and RE the graduate engineer and the senior engineer) created and used representation-bearing artefacts ‘on the fly’ (the work record, the teams’ file, sketch, and leaflet). This involved the use of different channels of communication (spoken, postal, and telephoned), each with different qualities for the transmission of the information. This process was not specified in the operating procedures laid out by the construction company, and was generated and interpreted creatively by the participants. In this way, the organisational structure functioned as an (incomplete) resource, rather than an absolute rule set, and it was loosely applied as a resource in the performance of work. It did not determine the physical actions required, which were selected according to a range of other factors (social, material and spatial).

This was by no means an isolated incident; many of the activities observed on the construction project were arranged ‘on the fly’, emphasising the contingent nature of collaborative planning and the *ad hoc* methods used to achieve this co-ordination. In

most cases, the standard operating procedures were used as a resource which the participants oriented their behaviour towards, but were not obliged to do so. Suchman (1987) addresses issues of rule use in detail; however this rule orienting behaviour is less apparent in the sorts of systems described in DC analyses, where an obligation to follow rules is more apparent.

The implications of this in the study of DC in highly complex settings are that the study will have to involve a wider range of activities than, for example, in navigational or cockpit co-ordination. The cognitive ethnographer needs to be aware of the SOPs, but also needs to understand how these are socially mediated within the context. Social action here is critical, and to focus on physical media and technologies is impractical - too many of the representations are located 'in the head' to understand the system without acknowledging them or their importance. Social mediation is of a far greater importance to collaborative action in these settings than that described in earlier studies of DC, which focus more exclusively on physical artefacts. However, for the analysis, there is a greater degree of uncertainty in investigating how people use representations mentally because these are not open to direct inspection. Resolving this problem can only be achieved by an increased interpretive element in analysis. This may be supported by interviews with participants in the functional system - asking people what they were doing or thinking. This is less precise in showing how work is achieved than the direct observation of a visible representation, but is no less interesting as a phenomenon or less useful to system designers.

Cycle duration

The cycle duration on the construction and design of the temporary works was highly variable - in terms of the project as a whole, the work was expected to take three years; far longer than the cycles of navigational fix taking. However, within this project, a number of smaller problem solving systems could be identified, each of which could be examined as a functional system in its own right. These different classes of problem ranged from specific temporary works designs (such as scaffolding towers), permanent works designs (ranging from pile placement to whole bridge designs), individual concrete pours, and so on, taking place over widely differing time-scales.

Similar tasks could also take place over radically differing time-scales. These were dependent on the availability of information about the problem, the intellectual problem solving resources, and the physical resources available to the functional system. Examples of this are impossible to demonstrate with snippets of observational data, and it is perhaps unnecessary to attempt to do so. The three year example of the project is itself an ample demonstration of cycle duration in a design and construction project; work took place over an extended period of time, characterised by periods of inactivity.

For the analyst, the long duration of a project presents something of an obstacle: the complete design and construction project took far longer than the time available to study it. A three year long project is by no means unusual in the construction industry, and similarly long project durations are relatively common in industry in general. It is therefore unlikely that a study could be made of the process as a whole within even a medium term research project. This must be contrasted with the observations and analysis of navigational fix cycle or cockpit behaviour, which could be measured in seconds or minutes. Whilst similarities exist in the abstract nature of problem solving itself, the practicalities of this difference between the two kinds of settings could not be more different.

The implications of this for DC are that the cognitive ethnography cannot be a complete study of the work process, but only a part of it. Data will have to be collected from before the study, and the analyst will have to envisage how it will be continued following the field study by projecting their findings forward. In comparison to the

previous studies of DC, there will be little chance of looking at another problem cycle to see how differences occur. However, it is possible to compare the management of activities between two organisations - something that was done in the construction study, although not described here.

Problem solving dynamics

The example below illustrates some of the mechanisms used to resolve problems in the design and construction process. The process is complicated because the problems are highly dynamic and unpredictable, and they are consequently difficult to plan for in advance. As noted in the section on cycle duration, the design and construction cycle also took so long that the original parameters or constraints on the process could often change. Amongst numerous others, these changes included modifications to construction law, new construction materials becoming available, and the corporate level changes that occurred over this time period. This was not the case with the previously examined cockpit and ship navigation systems - the participants do not face unpredictable situations, nor do they need to know about unpredicted changes to the task resources and problem structure that might take place within an activity cycle.

An illustration demonstrates how hard it was for the construction team to develop effective precedents to behaviour and why such precedents were not always useful because they could be overtaken by events. The example shown in box 6 demonstrates how an engineer communicated a design problem to the senior engineer. The graduate engineer had been gathering information about the conditions on the site and discovered a problem with the partially constructed bridge (from fieldnotes):

A graduate engineer had spent several minutes poring over a drawing, taking measurements of the planned gradient of the surface of the bridge. These measurements were transferred onto a sketch. The measurements on the sketch were in a different format to that of the original drawing: whilst the original drawing had been an overview of the deck (viewed from above), the sketch was a section through the structure (viewed from the side).

In addition to the different aspects of the drawing and sketch, the axes on the sketch were chosen so that they exaggerated the gradient and made deviations and discrepancies in the data more easily visible: the horizontal axis was on a scale of 1:250, whilst the vertical axis was 1:10. Information from the actual conditions on the site, taken with geotechnical equipment, and previously recorded on another table were then also annotated onto the sketch (figure 2).

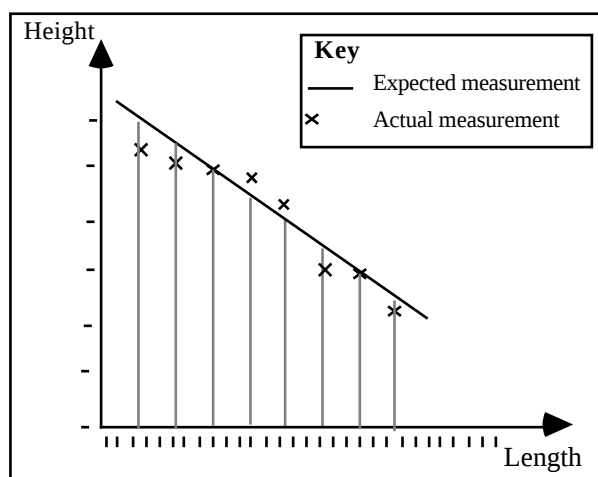


Figure 2. Sketch of road gradient.

On completion, the graduate engineer left the sketch on the senior engineer's desk, with a note attached to it explaining that he had found a discrepancy between the expected and actual gradient. The note further commented that he was going to be away from his desk for the rest of the day, but informed the senior engineers that he would be working at a particular location if further information was required.

Box 6: the transformation of a representation in communication.

In the terms of DC, the example shows how information was transformed from the design drawings and site onto different representations (tables of measurements), and then onto a graphical representation (the sketch) that more clearly demonstrated the relationships between the two data sets. The sketch shows that the measured slope had a gradient that did not match the gradient on the drawing. The form of this representation clearly demonstrated this discrepancy, through the difference that was exaggerated on the differential scales of the axes.

What is noticeable about the example is the way that the task involves both formal (i.e. established) work practices (in the creation of the drawing) and an *ad hoc* approach to collaboration (leaving the drawing on the desk with a note). Showing that work involves formal, or explicit, and informal, or tacit, features is not itself a novel finding in workplace studies (Grudin, 1994). Nonetheless, this activity differs significantly to the practices noted in previous DC analyses of work, in which the formal characteristics of work are exaggerated because of the particularities of the situations examined.

Recognising the unpredictability of work and the participants' use of *ad hoc* work practices to deal with this is a critical feature of examining work in the analysis of highly complex organisational settings. The interrelationship between the formal and *ad hoc* work practices is important in understanding work. Whilst Hutchins (1995a,b) and to an even greater extent Fields *et al* (1998) place emphasis on the formal or proceduralised aspects of work, they do not ignore the informal aspect of collaboration entirely. However, the particularities of the type of setting described in this paper have a far more critical role played by the participants' ongoing orientation to the constantly shifting problem situation. Their access to a wide range of resources and the flexibility in the management of their own work organisation means that the actors in the functional system are likely to exhibit many unique, situation specific solutions to the problems they face. Use of the DC approach in these settings must reflect this lack of precedents in work and the artful use of the resources at hand that actors make use of.

5. REFLECTIONS ON USE OF THE TECHNIQUE

The fieldwork demonstrates how the computational architecture of the design system arose through the relationships between the agents, where the transformation of problem situation into design solution involved a computation. In the field studies this was implemented within a distributed cognitive architecture, incorporating a number of agents with different skills and roles, in combination with a range of other representational media, and operating in an environment rich in resources to structure these transformations. Social and organisational co-ordinating mechanisms were used, in concert with the physical resources and constraints of the setting, which together determined the outcomes of these computations. However, there are a number of issues that need to be highlighted when of doing an analysis of this kind, and these are discussed in detail below.

The examples presented from this study clearly demonstrate some of the differences between ship navigation, aircraft cockpits and the other more limited situations in which we have seen problem solving examined through the use of DC. Most noticeably, the work is heavily contingent, and the participants make extensive use of the

representational resources that they find around them. Whilst the engineers made plans, and organised labour and materials in an attempt to control the situation (the ‘planned’ component of activity), they were also constrained by the context within which the activity occurred. This involved adjusting their ongoing behaviours to the evolving circumstances on the site and making use of the resources available. This is not to say that previous studies of DC did not account for this contingency, but that it is more exaggerated in these highly complex organisational systems and requires a greater degree of attention.

The descriptions of action in the earlier sections focus on the informational transformations that take place, as representations are re-represented in various media. In most respects this is identical to the traditional form of DC. However, in this study, snapshots of activity were collected and presented that were far more context-dependent and unpredictable than the kind of actions that take place in highly constrained environments. It is not the theoretical framework of DC that differs in this, but its application³.

The use of DC allows aspects of the information processing structure of the functional system to be made explicit. However, in a study such as the example given in this paper, the data collection and its analysis encompass the whole range of information processing activity that the functional system is capable of performing. What it demonstrates is how, *in the situations observed*, the resources were applied to perform representational transformations achieving the system goal (or possibly failing to do so).

As researchers examining large and complex organisational systems, we cannot fully specify the structure of a functional system. In the terms of cognitive science, the external symbol system derived will be incompletely specified and it cannot give us the granularity that Hutchins (1995a,b) provides us with in a formal, functional structure of the activity. In practice, the wide scope of the organisational systems analysis means that the ‘density’ of the data collected and the coverage of the analytic methods and approach is far lower than the standard DC approach can provide us with. In a large organisation, we have no means of examining all transformational actions in the functional system. Moreover, the interpretative nature of ethnography does not lend itself to this worldview (Perry, 1999). A realistic approach is therefore to do one of three things:

- (i) We can reduce the activity examined to a subset of the complete activity. However, such an approach means that we cannot see how the activity as a whole is performed.
- (ii) We can accept that the level of granularity in the analysis will be lower, and that the descriptions of the actions performed will be less detailed. The analysis will explore the higher-level, organisational features of work rather than its practice. However, this approach means that we cannot look at the actual *use* of the representations and processes in detail.
- (iii) We can focus on the significant actions that the participants deem to be of particular importance to the performance of the functional system as a whole – whether it is particularly difficult, important to their co-ordination, where they have particular problems, or have to perform repair functions (i.e. resolve breakdowns) in particular situations.

This third option is the one that we would advise, and have used ourselves. It allows a degree of scope for the analyst to select aspects of the functional system that are

³ In the terms of ethnography, its *representation*. Use of the word ‘representation’ is distinct in meaning to its use in DC, where it is applied to the symbol processing activities conducted in the functional system, and not by the analyst.

particularly significant to the participants, and to do a deep analysis of the representational structures involved. However, this will not provide a complete description of actions in the functional system, and may be prone to a degree of subjective bias in the actions selected for detailed analysis. It relies to a greater extent on the importance attributed to situations by the ethnographer and participants than the standard DC approach, but this is generally an accepted component of interpretive research (van Maanen, 1988; Hammersley and Atkinson, 1995; qualitative research book??), and is not, by itself, a failing. The method of data collection and its analytic framework suggested provides a means of examining aspects of information processing in organisational systems. It cannot be treated as a total description of work, but is a means of getting a deeper understanding about the activity within its context.

The application of this third approach is influenced strongly by the key dimensions of difference highlighted earlier. We suggest several features in the analysis of highly complex organisational settings that differ from the traditional approach used and propagated by Hutchins and other DC theorists:

- 1 The DC analysis is useful to illustrate how and which resources are used, but field data can only be understood as an instance of problem solving - at another time, work may be performed very differently because the functional system has access to a wide range of resources. It should not be presented as a complete description of an activity in the way that Hutchins describes navigation or cockpit activity.
- 2 Piecing together the component parts of the analysis is not a simple matter. Because of the size and complexity of the organisation being studied, the analyst will have to link a large number of interacting local functional systems together to form a picture of higher-level problem solving (in the case of this paper, temporary works design, rather than resolution of design sub-problems, such as the examples shown in boxes 3, 4 and 5). When doing the analysis, the cognitive ethnographer will need to identify, at an early stage as possible, which local functional systems form the 'trajectory of work' (Strauss, 1985), and to investigate these with an aim to linking them together in the final ethnographic report.
- 3 The cognitive ethnography cannot be a complete study of the work process, but only a part of it (over time, space and task) it that is extrapolated to cover the whole problem solving cycle (a related point to 1 and 2. above). The analyst is unlikely to be able to examine another problem cycle to see how differences occur. However, it may be possible to study another organisation to compare activities - not as a means of data triangulation⁴, but as a cross-cultural study.
- 4 The situation studied is ill-structured and, as a consequence, the participants strive to understand the nature of the problem and their co-workers orientation to the problem. The focus of the study is therefore as much on system self-organisation as it is with directly looking at problem solving. The analysis needs to pay particular attention to how actors in the functional system are made aware of ongoing, but problem-unrelated, situation monitoring than in a traditional DC analysis.
- 5 There is a need to pay particular attention to how standard operating procedures are used as resources, and not as absolute behavioural rules. In particular, the analyst needs to address how social interaction and negotiation are used to mediate action, and how *ad hoc*, or informal, approaches to dynamic problem situations take place. This will place an increased importance on interpretive analysis, where the analyst makes observations based on the experience of their immersion within the setting, rather than on direct observation and quoted examples. Interviews with participants,

⁴ Because we are not trying to produce absolute answers to questions about work organisation, but a *better understanding* about work in context.

asking people what they often did or thought about their work systems are one means of doing this - although they have not been used in the observational work described in existing studies.

Needless to say, there are likely to be many more equally important issues to discuss, but these represent a few of those that our experience has led us to consider as particularly significant.

6. APPLICATION OF DISTRIBUTED COGNITION TO DESIGN

The central concern of user-centred systems design lies in supporting work through appropriate technology, and goal centred descriptions of work can provide a means of achieving this. A distributed cognitive analysis shows how representations are acted upon and processed using social, technological and situated resources. By considering the information-processing element of work, components of the activity that relate to the goals and task alone can be highlighted. These focused descriptions of work have direct application to systems design, by showing technology developers *how* work is performed within its settings of action.

The results of a DC analysis have the potential to provide system designers with valuable information on the problem solving processes that are enacted by the functional system. The approach focuses on the representations and processes of work, and demonstrating how these are used in transformational activity (i.e. *situated* problem solving). By making explicit the artefacts on which computational operations are performed and the social practices used to transform the representations, systems developers can build systems that are appropriate to the informational needs and requirements in performing their work itself.

Two central components in DC - representations and processes - are useful to studies of technology-mediated work and to systems design, because they can help identify the goal-directed aspects of the work activity (Perry, 1998b). Examining systems as having an initial state, goals, inputs, outputs, information-representations and information-transforming processes can be used as a common frame of reference between the analyst and technology developer for communicating design-relevant information. Good systems design is concerned with building computer systems that are not only functionally adequate, but are sensitive to the social, situated, organisational and cognitive aspects of the work. DC, as applied in complex organisational settings of the kind described in this paper, is a highly promising means of informing designers about these aspects of work. The focus of DC on the representations and processes of work enables the analyst to describe the *ecology* of organisational work systems, in settings that are rich in organising structures.

It is not the purpose of this paper to make explicit reference to the design of technology, but there are a range of links that can be made from the data to technology design for the organisational system described in the example. One of these is planning for contingency – when we develop computer systems, there is a tendency to apply a simple approach, often with a sound user-centred rationale. However, in practice, we do not often work as individuals, but in an artefact rich and social environment. Making a computer system simple to use by cutting down on apparently overcomplicated or redundant methods could lead to the loss of information from that work system. Consider the case of the graduate engineer who overheard the senior engineer on the telephone (box 4): if this system had been automated using technology (such as email or a web based form), it would not have been possible for the material to have been ordered as easily. In this case, a separate order of concrete would have had to be made, tying up resources and losing the economies of scale that come with a large order.

7. CONCLUSION

The role played by DC in the past has not allowed researchers to examine organisational systems outside tightly specified systems of activity. The possibilities that DC offers as a framework cover a far greater range of applications than this because many organisational activities can be characterised as involved in information processing. We have therefore re-examined the methods used by Hutchins and questioned their appropriateness in these new domains. We challenge the methods that have so far been applied to it and apply the technique in these new contexts and application areas.

A core difference between the sorts of distributed cognitive analysis performed in this study and the sort of study performed in closed systems is that we do not attempt to describe a complete computational structure for the functional system. Rather, we look to the framework of distributed cognition as a means of exposing the information processing aspects of work by the fieldworker or workplace analyst. Hutchins attempts to produce well-defined functional systems, capturing most, if not all, of the information processing characteristics inherent in them. However, because of the characteristics of the organisational systems that we are examining, this is not a possible option. The examples documented can only be what one reviewer has described as particular instances out of a potentially infinite sea of work practices, and they do not necessarily typify the functional system. What they do however, is to give an insight into collaborative problem solving behaviour and the use of artefacts in the performance of work.

Whilst we cannot be as precise as an analyst working with so called 'closed systems', this does not mean that the approach lacks value. Rather, it changes the remit of the analysis from providing a near complete specification of a problem solving activity into one that demonstrates how ethnographic data can be focussed. This focus on the information processing elements to show how representations and processes can be appropriated for use in co-ordinating distributed problem solving activity has direct implications for systems design in systems that would otherwise have to be analysed using different techniques.

Distributed cognition can be used as an analytic technique to structure and delimit the scope of the fieldwork. The framework of DC allows the analyst to examine the computational nature of work, and the problem solving activity that occurs over a distributed group of individuals and artefacts. The analysis lies not in the abstract processes of work, or in a description of the communications that made work possible, but on how the work and its co-ordination are inter-linked through task performance. In this, we do not seek to radically alter the foundations of the DC approach: distributed cognition is a broad church and does not advocate adherence to a particular method or approach to gathering data about the functional system (Hutchins, 1995a; Hollan *et al*, unpublished). However, as yet there are no well thought out methods to extend the approach beyond the areas that it has already looked into. This paper makes a contribution and gives suggestions as to how this may be achieved.

The importance of these studies to systems design and CSCW lies in the descriptive power that they have in making explicit the collaborative problem-solving element of work. This is the area that systems designers need to support, because it is the very reason why the participants are collaborating. By seeking to understand the transformational nature of work we can begin to design effective and appropriate technology for that work. Opening up the application of the DC approach to a broader range of application areas is one way that we can help support this.

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The organisational study provides a central focus with which to determine the theoretical and methodological areas of DC that need particular consideration and possible extension, and those that seem appropriate in their current form.