Paper-Supported Collaborative Work

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Technical Report EPC-1995-109

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Using ethnographic studies, we show how paper is integral to collaborative work in three very different organisational settings. Reasons for the use of paper as opposed to electronic alternatives are analysed in terms of the local aspects of interaction it supports, and also the ways in which use of paper has evolved hand-in-hand with organisational work practice. The implications of these findings for the design of collaborative tools are discussed.

Introduction

Observation of any organisational setting only serves to confirm that the most pervasive, ubiquitous artefact in support of collaborative work is paper. Even in "high-tech" research environments, paper is everywhere. We write on it, read from it, stack it, and file it. We also bring it to meetings, exchange it, distribute it, and discuss it. Far from replacing paper, the emergence of new, digital technologies appears to have encouraged its proliferation, easing the creation of paper copies from digital or paper forms. What is it about paper which makes it such an integral part of work? Why has the paperless office not arrived?

There can be no simple answers to these questions. There are reasonable arguments which point to factors such as habit and cultural preference playing a role, as well as technological obstacles to converting paper into electronic forms, or in incompatibility amongst electronic media. However, we believe that two significant reasons for the persistence of paper in the workplace relate to the role of paper in supporting collaborative work practices. Specifically, the reasons can be summarized as follows:

(1)   Paper has physical properties which make it particularly well-suited to supporting some important aspects of collaborative work. These particular

properties are not satisfactorily provided by any other medium or collaborative tool.

(2) Organisational work practices in a variety of domains have evolved hand-in-hand with the use of paper. Paper has helped to shape work practices, and work practices have been designed around the use of paper.

In the following we illustrate these two points using the findings from three different ethnographic studies. We then show how consideration of the ways in which paper supports collaboration can contribute to the design of technological tools for collaborative work. This may not only help explain why attempts to replace paper-based systems with screen-based systems often fail, but may also help pinpoint what aspects of paper need to be considered in the design of electronic tools. Further, as the examples taken from each setting will show, we need to consider more than the ways which paper supports the local aspects of collaborative interaction. We also need to consider the ways in which paper is part of broader organisational aspects of work, and to consider that replacing paper-based systems with computer-based systems may require a re-specification of organisational context in addition to re-designing aspects of the local interface.

A Review of the Literature

Most of the literature concerned with behavioural interaction with paper comes from psychology, and therefore, unsurprisingly, tends not to consider the role of paper within collaborative activities. Rather, such studies are mainly concerned with an individual's use of paper, and with systematic comparisons of behaviour with paper versus screen-based media. For example, a substantial subset of this literature is concerned with the presentation of text in controlled laboratory settings and focuses on issues such as ease of reading, navigation through text, and manipulation of text (see Dillon, 1992 for a review). Other laboratory-based comparisons concern the writing and composition of text on paper versus screen (Card et al., 1985; Gould, 1980; Haas, 1989).

In addition to laboratory studies, observational, interview, and questionnaire techniques have been used to examine how people use paper to organise information in their offices (e.g., Cole, 1982; Lansdale, 1988; Malone, 1983), and have been used in comparing paper and electronic calendars in office work (Kincaid et al., 1985; Payne, 1993). Other studies focus on the impact of converting from paper to electronic media for patient records (Pettersson, 1989), magazines (Koons et al., 1992), and books (Egan et al., 1989; Leventhal et al., 1993; Marchionini & Schneiderman, 1988; Mynatt et al., 1992).

To learn more about the affordances of paper for collaboration, we must turn to field studies, mainly sociological, which examine the role of artefacts and technology in supporting collaborative activities (e.g., Bowers, 1994; Kidd, 1994; Rouncefield et al, 1994). Of most direct relevance is the work of Luff, Heath, and Greatbatch (Luff et al., 1992) who have examined the use of paper and screen-based documentation in three

different settings: an architectural practice, a medical centre, and a London Underground control room. Luff and colleagues give a detailed description of the ways in which paper documents form an integral part of collaborative work. For example, they discuss how the ease of annotation and marking on paper, and its general tailorability, means that taking notes can be interweaved with ongoing activity. They stress that paper has "ecological flexibility": it can be moved around, handed over, distributed within the local environment, and used as a focus of discussion and coordination. This can be contrasted with the relative immobility of screen-based applications which causes localisation of activities around the screen, and which causes participants to break off from an ongoing collaborative activity to attend to the screen.

Approach

The observations that Luff, Heath and Greatbatch make are mainly concerned with the role of paper in supporting aspects of collaborative interaction within the local milieu of the work environment. In the following discussion, we present examples from three different organisational settings which largely confirm their findings. However, using these example we also seek to extend our observations on the use of paper to include an assessment of its role within a broader organisational context.

The three settings that we draw from are: the London Air Traffic Control Centre, a police constabulary in the U.K., and the International Monetary Fund. In all three cases, the field work was carried out by R. Harper using ethnographic methods. Each involved long periods of observation, lasting up to six months. In each case, the purpose of the field work was to understand what ethnomethodologists, following Garfinkel (1967), call 'practical reasoning'. This practical reasoning reflects both the local circumstances in which individuals operate and the organisational frameworks that provide the broader context of work. Through examination of work as it "naturally" unfolds, the intersection of local practice and organisational requirement was specified.

Furthermore, each period of field work was selected to coincide with the introduction of new electronic systems offering various alternatives to the paper-based media previously used. The introduction of these systems resulted in some movement away from paper, but in no case did it result in its complete abandonment.

I. Air Traffic Control

Air Traffic Control (ATC) is renowned for its technological richness. It may be surprising, therefore, to discover that paper remains central to ATC systems. This is particularly the case with the system operated by the London Air Traffic Control Centre (LATCC). While the operations of this centre have been reported quite extensively in the CSCW literature (e.g., Harper et al., 1991), here we want to focus on those findings that highlight the role of paper flight progress strips in ATC. But we also want to extend these findings to show that the organisation of the airspace that LATCC controls — more or less covering all of England and Wales — has evolved hand-in-hand with the use of these paper flight progress strips. We will argue that paper not

only supports the local interactional of controlling, but also supports and reflects the broader organisational system of which that work is part. Specifically, we want to argue that the degree of complexity of individual controller decision-making at LATCC requires that it be supported by team work. In turn, the use of paper strips is required to support this collaborative activity.

The Local Organisation of Controlling Work

The airspace in England and Wales is broken up into 'sectors', each of which is the responsibility of an individual controller. As aircraft move from one sector to another, so responsibility for those aircraft moves from one controller to the next. This division of the airspace is broadly reflected in the physical layout of the operations room at LATCC. Presently, en route control is effected within a hall which is divided into North and South banks, each further divided into 'suites'.[1] A suite contains two radar screens, a variety of VDU's, data entry consoles, printing machines, and the flight progress strips which are placed on racks just above the radar screens in full view of the entire team. Typically about five people are assigned to one suite (one chief, two controllers and two assistants), though this can vary widely.

The achievement of controlling turns around the effective use of the flight progress strips — pieces of paper about one inch wide and eight inches long that are formatted into 'boxes' containing information about individual flights. The information is derived from the original filed flight plans for each aircraft contained in the computer database. In this regard they are historical, but they actually display real time data because sector suite staff move them about the racks, mark them, and in other ways use them as an ongoing feature of their work. These practices result in the racks of strips being an accurate representation of flight movements in a sector, and at the same time, an accurate representation of the activities of all those persons working on the sector (Harper et al., 1989).

Above and beyond these specifics, however, the work on and with flight strips is the manifestation of a working division of labour. So, for example, when a controller marks something down on a strip, this enables others who depend upon the controller to know what he or she is doing. Similarly, others such as the chief, can mark things down so as to inform the controller. This marking and movement of strips is a continuous process, interwoven with all the activities around the suite. A particular concern is that all those who work around the controller can tailor their activities so as to ensure that the controller does not get overloaded. They look at the strips and at what the controller is doing, and on that basis, assess what jobs they can do. Their concern is not to interfere with the controller, but to systematically reduce any excessive workload for the controller. In this sense, a controller is placed in a "cocoon" ensuring that he or

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[1] The London Terminal Manoeuvring Area (TMA), which until recently was operated from two suites in the main hall, is now controlled from a separate room operating a different system in which airspace is not sectorised but organised into corridors or 'tubes' of airspace. For the most part the following discussions relate to the en routes sectors at LATCC.

she can concentrate solely on the job of controlling. We shall come back to this shortly (Hughes et al., 1988).

The Advantages of Paper Flight Strips

Over the years, numerous attempts have been made to introduce electronic forms of strips. An important motivation behind these was the aim of maintaining more accurate and up-to-date data about flight movements into the flight progress databases, which could provide accurate collision alert systems, amongst other things. None of these attempts resulted in major changes in the systems at LATCC, however. Most were rejected during prototyping and trials. In particular, these systems were rejected because it was felt that they reduced the speed with which controllers could work and undermined the effective operations of the division of labour of which controllers are part.[2] In summary, the staff had no trust in the new systems.

Looking more closely at ways in which the paper strips are used reveals a number of reasons why the electronic systems did not provide a comprehensive alternative to the paper medium. One important quality of paper strips is that they can be laid out in space to provide at-a-glance information simultaneously available to all members of the team. For example, the amount of flight activity in a sector can be seen by the number of strips in a bay: the more there are, the busier it is. Another affordance of the paper strips is that a chief can "cock out" a strip from the bay so as to draw the attention of the controller. No mark is made on the strip, but its distinct physical orientation gives it a special identity. On similar lines, the physical ordering of strips may be easily changed, so when variations in actual speeds of aircraft result in the relative positions of them being different from planned, the strips can be moved accordingly. In many senses, then, the paper strips have a flexibility and tailorability that supports the organisation of work within a division of labour. Conventional electronic display media do not provide the capacity to take advantage of spatial layout in the same way — information must be laid out within a small, immobile screen. As a result, much of the important information that comes from the paper strips is either lost or must be presented in new ways (Shapiro et al., 1991).

Another aspect of the paper strips is that interacting with them can be interwoven with other activities. For example, as noted, one feature of the strips is that they are constantly being marked. An advantage with paper is that marking is easy and direct, whereas keyboard data entry can be slow and cumbersome. With paper strips, such marking can be done while engaging in other activities, such as discussion with colleagues or with pilots. The ability to do concurrent activities is especially important at times of high workload.

A final but crucial point is that the use of the paper strips makes the activities of individuals (such as the process of marking) visible to the other parties. Knowing what other members of the team are doing is vital as interdependence of activity is part and parcel of the work on and around a control suite. For example, a controller needs to

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2   An exception was RD3. See Harper et al. (1991).

know that the chief will notice when he or she marks a new flight level on a strip since the chief may be in the process of negotiating a hand-over level that would be impacted by this decision. The fact that the paper strips are physically laid out in space means that the activities of co-workers interacting with the strips can be perceived, providing mutual awareness for collaboration. As Luff et al. (1992) have pointed out, screen-based activity, in contrast, is much more localised so that the nature of any team member's activity is more inaccessible.

The Organisational Context

In addition to the affordances of paper in supporting local aspects of controlling, it also needs to be recognised that this local work is a reflection of the organisational structures of which it is a part. The need to cocoon controllers is a case in point. Creating a cocoon is necessary because the current procedures in LATCC airspace can make for extremely complex decision-making.

In brief, the reasons for this complexity are as follows. As already noted, controllers have full responsibility for aircraft travelling throughout each sector, each of which covers quite a large volume of airspace. Extensive regulations and procedures provide a framework in which controllers operate. However, at LATCC, the airspace procedures do not provide a strict and tidy environment; indeed quite the reverse: at times the procedures can make for difficulty, sending aircraft to the same place at the same time. As a result, sometimes controllers resort to standard procedures to organise air traffic, but more often, they must modify these with their own ad hoc organisation. Controllers achieve, if you like, an order in the sky through the skilful operation of procedures, contingency and their own ingenuity.

The complexity of such decision-making can vary enormously. Sometimes just two aircraft can absorb a controller's concentration; at other times a controller may be able to manage fifteen. What is absolutely crucial at any moment in time is that the controller does not get overwhelmed or, as the controllers themselves put it, "lose the picture". It is the team of individuals who work alongside the controller that ensures that a controller never reaches this threshold.

We have seen that the paper strips are fundamental to this process. It is the strips, constantly changing and being altered, that are the devices that ensure that the cocooning gets done. Their role in this, their effectiveness as information representation media, has developed hand-in-hand with the development of airspace procedures and work practices at LATCC. Without paper strips, it would be more difficult to support a flexible working division of labour, resulting in controllers being less able to deal with complex air traffic control situations. Designing out the paper strips would require reducing the complexity of the work. This might be accomplished by more restrictions in the airspace, whether they be in terms of amount of traffic in any sector, or in relation to the configuration of airspace movements that the procedures allow. This situation would be similar to some ATC systems in the USA. Here, aircraft are obliged to fly according to very confining flight paths, in strict sequential order, and on tracks with no intersections and cross-overs. All controllers need to do is supervise the respective

speeds of aircraft. For this reason, controllers in these ATC settings do not need the same support on and around the suites as do controllers at LATCC. In some cases they work more or less on their own, irrespective of the busy-ness of their respective sector. Significantly, they have no need for paper-based flight strips (although, as it happens, they keep simplified copies of them for back-up and litigation reasons).

II. The UK Police

This study was primarily of a mid-sized "shire" constabulary in the UK, supplemented by studies of two metropolitan forces and a second shire force. Ethnographic observation was conducted over a three year period commencing in 1987. A particular focus of the study was uniform patrol work and crime reporting. During the period of observation, the constabulary attempted to transfer a paper-based crime reporting system to an electronic one, but this resulted in uniform officers adopting a mix of paper and electronic forms in their crime reporting activities. This mix, and in particular the continuing use of paper, was in part a result of resistance to change and habit, but more importantly was because of the specific affordances of paper that were relevant to uniform crime reporting work — features that supported both local interactional work and the broader organisational process of collaboration of which that work was part.

To understand why uniform officers prefer paper at some points in the life cycle of crime reports, one needs to consider the social processes during which uniform officers interact with the public, the process of preparing crime reports, and how the resulting crime report data provide a basis for broader organisational collaboration.

Interacting with the Public and Making Crime Reports

Uniform officers may be distinguished from CID and other specialist branches in being the individuals who provide the first point of contact for members of the public. Not only is it uniform officers who patrol the streets, but usually it is uniform officers who will respond to calls from the public, and who service the front desk of police stations. Uniform officers are, in effect, the public face of policing.

When uniform officers visit those persons who have reported crime, or when they deal with individuals at the front desk, the actual process of creating a crime report is a delicate matter. It is not simply a question of filling out a form, but involves dealing with people who are often distressed and sometimes confused. Moreover, it is a process during which the uniform officer has to give an impression that everything that can be done will be done. Uniform officers must react and deal with a member of the public in ways which adequately reflects that person's concerns (Manning, 1977).

For these reasons, the artefacts used to create a crime report are important. For example, one of the shire forces studied introduced lap-top computers for use in commencing crime reports. These would be used by uniform officers to enter data which would be downloaded to the main database. Information technology managers perceived two advantages of this device: (1) that it would expedite transmission of data to the constabulary's networked mainframe, and (2) that it would give the impression to

the public that the force was taking full advantage of the latest technology. However, the officers who used the equipment for a trial period more or less unanimously rejected using it on the grounds that the lap-tops made dealing with the public difficult. In particular, they felt that they spent more time working their way through the templates on the lap-tops than they did listening and talking to the victim. It was, as one of them put it, awkward. But more importantly, using the machines undermined the officers' ability to attend to their main priority — to manage the interaction in a way that conveys the right image to the public. The lap-tops certainly conveyed an image of a "high tech" constabulary, but it also conveyed the sense of a force that was more interested in the technology than in the concerns of the public.

This example has much in common with the findings of Luff et al. (1992) in their study of a medical practice. They found that with paper, document-related activities could be interwoven with other activities. In the case of police work, this means interweaving activities like the continuing conversation that the officer will have with a person who reports a crime. The psychological state of that person may be such that police officers have to be extremely alert and sensitive to the ebbs and flows of what is said; pauses may be a manifestation of stress as much as a simple mechanical feature of account-telling. This needs careful attention. A police officer who asks for a victim to stop telling their tale while they fiddle with their computer would be undermining the very thing that the police officer is there for: to allay the victim's fears, to provide encouragement, and to re-confirm the fact that society will protect them and punish the wrongdoer (Ackroyd et al., 1992). Of course, uniform officers are variously successful at this, and moreover, achievement of this "theatre" as one commentator has called it, is very difficult to train for or to assess (Manning, 1977). It is one of the unspecified but essential skills of good police work.

There are additional features of crime reporting that paper supports which electronic alternatives do not. For paper provides at once an ease of mobility, an ease of access, and a physical form that makes it ideally suited to the general organisation of uniform police work. For example, paper can be accessed wherever the uniform officer finds him or herself, whether in a victim's home, a shop, a night-club, or the street. Not only is it highly mobile, it is also unconstrained by the setting in that one need not be near a terminal, in good light, or near a mains plug. Moreover, an officer can "file" a crime report in his or her pocket as he or she leaves one place, to be retrieved and accessed when the officer has more time. This time might be later when they wait in their patrol car or it may be back at the station at the end of the day. Finally, it is in the nature of uniform work that things can get damaged: an officer may get involved in a situation where he or she will have to use some physical force. Paper is again suited for this: it is not heavy and fragile, and can be put away rapidly.[3]

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[3] Of course, some of these individual functionalities can be adequately supported by electronic forms. For instance, the lap-top that one shire force developed was remarkable for its robustness. It had been designed to be "uniform officer proof" meaning it could be dropped on cement, sat on, kicked and left in the wet, and it would still work. But at the same time and as a result, it was heavy, would get in the way, and was most unsuited for some of the physical circumstances uniform officers can find themselves in.

The Organisational Context

The above relates the local nature of uniform activities with broader aspects of the prioritisation of their work. But another example is perhaps more effective in showing how paper links the local practice of uniform officers with broader organisational goals.

Amongst the purposes of keeping a crime report is to produce statistics, information about workload, and information for proactive policing. Various new electronic information systems have been introduced to help facilitate these goals, improving the dissemination of information around the force, providing better search and retrieval functionalities, and so on. In one instance, the main shire force studied introduced a centralised crime reporting bureau. This required uniform officers to telephone the bureau as soon as possible from the crime report scene to initiate the report process. This could mean telephoning from the victim's home or even from a public telephone if a report was being made on the street. The purpose behind this was to make available the data as quickly as possible. But in practice, officers rejected the system and instead maintained their use of paper. The reason for this was the paper was providing an important affordance. In essence, it was serving as a holding mechanism whereby uniform officers could control the delivery of a crime report into the electronic database.

Uniform officers often want to hold on to a crime report until they are satisfied with it. Often, crime reports are not completed during the first meeting with a person who reports a crime, for police officers may have to respond to another call from the public making it necessary to cut short the reporting of the first crime. Another consideration is that it is sometimes difficult to accurately categorise an incident. When someone reports that they have had a door smashed through, it sometimes remains unclear whether the incident was "breaking and entry" or a "burglary". It is only a burglary when something it taken and it may take some time for a victim to discover whether something is missing. Thus, the delay in entering a report is not so much to ensure the satisfaction of the individual officer, but to ensure that the crime reporting system is an accurate and useful device for the organisation as a whole. In this sense, the concern with accuracy reflects a concern with the collaborative process that crime reporting supports.

Alteration of the medium through which reporting is accomplished can affect not only an officer's autonomy, but can also affect the importance of crime reports for the organisation as a whole. For example, when the force introduced the new centralised crime reporting system, not only were interactions with the public made more difficult, but it affected the nature of crime information. Instead of the data being more accurate, it became the reverse, since crime reports entered the system prior to being revised and corrected. Moreover, even once these corrections were made, as a natural function of the system, an audit trail of correction left an embarrassing impression of a force in which officers were often unable to categorise crime. Combined, the new system resulted in the crime reports being less useful for officers in their inquiries, and had the politically disastrous consequence of making the force seem incompetent. Within weeks of the system being introduced, police officers began to work around the system reverting back to their use of paper.

It needs to be made absolutely clear that the argument is not that paper is universally better than electronic alternatives in this domain. Rather, the argument is that specific aspects of the crime reporting process are better supported by paper. Other aspects of that process, such as data analyses and searching procedures, are clearly much better supported by electronic means than paper media (see Harper, 1991). Our purpose is to draw attention to the much misunderstood and under-emphasised role of paper in fundamental aspects of work practice. Police officers use paper for certain aspects of their work not because of habit and cultural preference, but because it makes good organisational sense to do so. For this reason, current work practice reflects a collage of paper and electronic forms — a collage which is determined by both the local interaction detail of work and the organisational framework of which it is part.

III. The International Monetary Fund (IMF)

The IMF, based in Washington D.C., is a financial 'club' whose members consist of most of the countries of the world. Member countries contribute to a pool of resources which can then be used to provide low interest, multi-currency loans should a member find itself facing balance of payments problems. The IMF has some 3,000 staff, of which 900 are professional economists. These economists analyse economic policies and developments, especially in the macroeconomic arena. They have particular interest in the circumstances surrounding the emergence of financial imbalances, the policies to overcome such imbalances, and the corrective policy criteria for making loans. This involves going on 'missions' to the country in question. The resulting assessments of member countries are contained in documents called 'staff reports' which are used by the organisation's Executive Board for its decision-making.

Like many organisations, the IMF has introduced a variety of networked, electronic document systems and tools only to discover that paper remains an important medium in work. Our observations suggest that there is a complex of reasons for the persistence of paper, which broadly speaking have to do with how electronic office information systems do not offer a complete and effective alternative to paper in the support of collaborative work. We will argue that staff at the IMF use paper at certain stages in their work not because of say, cultural preference, but because the functionalities of paper support and interact with important collaborative aspects of their work, both at local interactional level and more broadly, in terms of organisational requirements.

It should be made clear from the outset, however, that the aspects of collaborative work that we note are supported by paper are only part, and not necessarily the largest part, of what constitutes work at the IMF. The IMF's economists do use electronic document forms for a whole range of tasks. Our concern is not to argue that it is only paper that supports collaboration; it is rather to argue that paper supports certain aspects of collaboration. It is because economists use electronic forms at one point in their work, paper at another, that the IMF, like so many other organisations, finds that despite considerable investment in electronic document systems, work practices revolve

around a mix of paper and electronic forms. It is the reasons for paper that we concern ourselves with here.

The Production of Staff Reports

The business of macroeconomic analysis has a number of features which results in the IMF organising the work of producing staff reports in particular ways. Most importantly, as we will describe, the production of staff reports is heavily dependent on economists exercising their professional judgement. To ensure the adequacy of these judgements, the IMF is organised so that these staff reports go through extensive and thorough review. We will argue that paper has an important role in supporting these reviewing processes.

The exercise of professional judgement pervades the production of staff reports at many levels. For example, one feature of the data used in macroeconomic policy analysis is that they need to be as current as possible — to reflect, as much as possible, the present moment or at least the present quarter for a particular member country. This is far from a straightforward matter of data collection and analysis. Some figures for certain aspects of an economy will be available when they are needed, while others will not. Consequently, economists have to make estimates for some figures, doing so in part, by looking at historical trends in those figures (basically at what happened in previous quarters) and further, by reconciling these estimates against figures that they can be sure about. The important point is that matters of fact are immersed in considerations of interpretation, and gathering data involves the exercise of professional judgement.

A second feature of producing staff reports is that of determining and evaluating policies, particularly monetary policies. This process also involves judgement, both in relation to data, but also as regards certain assumptions about such things as growth of the internal and international markets, the impact of international inflation on internal inflation, about the various impact of policy alternatives, and so on.

Finally, judgement is required in determining the advice the IMF offers its members, and to ensure its consistency across countries. Since every country has more or less unique macroeconomic circumstances, this means that the IMF's economists have to reason carefully to ensure that this consistency is achieved.

To ensure that the best judgements are made, the work of the IMF's economists goes through extensive drafting and review. This is undertaken by the authoring team themselves, who will reiterate and redraft their documents again and again and who will spend many hours working through their arguments and materials. Review also occurs externally, most importantly by the Department of Policy Development and Review. This review process is very intense, not because mission teams make incorrect judgements, so much as because it is in the nature of policy work that issues need to be very clearly thought through and presented.

The Use of Paper in Review Processes

For our purpose, what is of relevance here is that important aspects of these review processes are supported by paper. Further, these paper-supported processes are essentially social, mainly consisting of meetings with authors and reviewers present. For example, economists collaborating on a staff report will engage in intense discussion of their documents, will revisit and re-order elements of their judgements, will consider how alterations in one judgement affect the rest, and so on. These processes are essentially didactic and co-participative, with for example, individuals explaining and persuading others of the rationale for their contribution to a paper. This same holds true when a paper is being reviewed externally. For here, although the reviewing team will spend some time going over the document on their own, a key event is to meet and discuss their interpretations together. It is on the basis of such meetings that a document is completed. We argue that paper is essential to these processes because it supports the social mechanisms that occur during these reviewing activities.

One reason paper supports the social processes of document-centred meetings has to do with the "ecological flexibility" that Luff at al. (1992) have described. The flexibility of paper supports the interweaving of discussion with activities centred around the document in a group situation, such as marking up or reading through parts of a document. These social processes surrounding the discussion of the document are vital, but it is equally critical that interacting with the document not disrupt this complex social interaction, or force participants to break away from any ongoing collaborative activity.

A second important affordance of paper in these situations is that paper provides at-a-glance information so that people who are co-present can discern the activities of others with respect to the document being discussed. Teams of reviewers can and do sit around desks arguing and discussing the documents in question, marking sections, pointing out parts, and exchanging pages in ways that reflect and support the local interaction processes. Paper helps them tell whether the person next to them is turning toward or away from the document, helps them see approximately where in the document they are, and tells them whether a colleague is flicking through pages, or is setting it aside. In part, it is the physicality of the medium and the ease with which it can be manipulated which gives a sense of the activities of others and helps the group co-ordinate and focus their discussion.

The Organisational Context

It is in these respects then that paper supports the local interaction related to staff reports. But this local interaction occurs within an organisational context, and is thus linked to the structural properties of the IMF. For we have seen that review is fundamental to the IMF because it ensures the adequacy of its decision-making. Without review, the IMF is ineffective.

These procedures for review have been developing over many years. If the foregoing analysis is correct, then paper will have been central to these procedures since

the beginning. In this sense one may say that the IMF has developed its organisational structures hand-in-hand with the technology of paper. By the same token, we can speculate that attempts to introduce new technologies which replace paper but which do not offer equivalent affordances will affect not only the achievement of the local interactional work, but will also impact upon the effective working of the institution as a whole.

For example, if the review process were restricted to the use of electronic groupware for the sharing and reviewing of a document, then the social mechanisms of review would be by-passed. And in turn, all of those benefits that are conferred by the act of meeting and discussing documents together would also be by-passed. To be sure, some of the IMF's economists would view fewer meetings as an improvement since they complain of the amount of meetings they have to attend already. But others would view this as perhaps worrisome, since the social interaction related to the review processes is a medium whereby individual economists are kept in contact with and participate in the ever-developing thinking of the IMF. For these individuals, the meetings that are for others a burden, are the very stuff that keeps the IMF intellectually vibrant.

Of course, these are just conjectures. But what our studies of the IMF have shown is that the idea of a paperless office in this institution is one that needs to be thought through very carefully. As with air traffic control, where paper helps to bind together working practices to support complex and highly skilled collaborative systems, and in police organisations, where paper helps enable individual officers to more effectively collaborate both with the public and their fellow officers, so in the IMF paper helps economists do their work in ways which ensure that their individual activity is effectively linked to cooperative and organisational action. Without paper, the IMF would be a very different institution indeed.

Design Implications and Conclusions

The preceding dicussion makes it clear that there are good reasons for using paper in certain stages of organisational work processes. To some extent, this can be traced to paper's physical properties. The fact that paper is tangible, flexible, and light, has a variety of implications for the ease with which it can be physically transported, manipulated and laid out in space. The fact that it is easy to mark and annotate, and that it displays fixed rather than dynamic information means that it is easily tailorable and shows a history of the ways in which it has been tailored. Finally, it is in the nature of paper that access to its contents can be physically controlled and monitored, as opposed to electronic media which may give access to a centralised deposit of information for many different individuals.

All of these properties have implications for the support of the local dynamics of interaction in collaborative work. The implications at one level are that paper can be easily moved around the environment. As we saw in the example of police work, its portability and flexibility is particularly suited to the job of a uniform officer. But more than this, the fact that paper can be spread out in space and physically manipulated

means that activities are made visible within a working team. In the case of ATC and the IMF, this visibility is important in supporting and coordinating local interaction. Further, it is this implicit information which paper helps to impart, along with the ease with which it can be accessed and annotated, that allows paper to support activities without disrupting them. This is important to all three of the settings we described.

The findings with regard to the support of the local dynamics of interaction mainly serve to confirm those observations already made by Luff and colleagues (Luff et al., 1992). What we have added, however, is observations about how it is that paper provides support for organisational processes. One implication of the fact that information is on paper, is that people can physically control who has access to that information. This turns out to be a useful affordance which showed itself in two very different examples. In police work, it meant that paper acted as a holding device whereby individuals could retain control over some information prior to entering a shared database to ensure its accuracy. In this example, paper provided a medium whereby the adequacy of organisationally distributed information could be guaranteed. In the IMF, the fact that information was on paper at specific points in the document life cycle meant people could not access its contents without being co-present. The fact that they had to come together to discuss documents of mutual concern supported the social processes which we argued are vital to the workings and intellectual life of that organisation. The role of paper in organisational work practices can also be seen in the example of ATC where the various affordances of paper, and the ways in which it supports local interaction, could be seen to reflect airspace and controlling procedures that have been evolving over very extensive periods of time. Here the microcosm of activity around ATC suites can be seen to be a reflection of the organisational setting in which it occurs.

In attempting to replace paper-based systems, the issue then is whether or not the affordances for interaction provided by paper can be embodied in new technologies which offer the added advantages conferred by digital technologies. In many respects, emerging technologies are becoming more "paper-like". Computing technologies are becoming more portable: wireless, and lighter in weight. Display media are offering better quality resolution within lighter and larger formats. All these facts mean that digital technologies will increasingly take on some of the ecological flexibility of paper. Furthermore, with developments in input technology such as stylus-driven input, and interaction techniques such as gestural and mark-up languages, we can look forward to interfaces that are easier to access and annotate, and which therefore may be less disruptive of ongoing activity. Other affordances of paper, such as the fixedness of information with respect to its medium, and issues to do with the control of access to information, also have an impact upon interaction, as we have seen. However, these issues are much less understood and deserve more attention.

An alternative approach is to accept the usefulness of paper and attempt to develop ways of integrating the paper and electronic worlds. Examples here include "glyphs" and associated smart paper technologies (Johnson et al., 1993; Rao et al., 1994), systems which incorporate scanning and projection such as DigitalDesk (Newman & Wellner, 1992) and systems for remote collaboration over paper via video connections

(e.g., Ishii & Miyake, 1991). This approach broadens the options for users, and helps to surmount some of the technical obstacles which often force people to choose between one kind of medium and the next.

But alongside considerations of aspects of the design of technology, the examples taken from the settings we have described also make the point that organisational work processes and the use of paper have co-evolved. Therefore, attempts to alter the role of paper, or to replace paper in those processes, will impact upon the organisation in more far-reaching ways than an examination of only the local aspects of interaction would reveal. Consequently, it is a step not to be undertaken lightly. The role of paper in organisational processes needs to be specified beforehand, much in the way we have attempted to do here, and on that basis an attempt to map out the future evolution of work processes can be undertaken. It may be that certain processes will need to retain the use of paper, at least for the foreseeable future. Others may need to be redesigned in ways that gradually reduce the need for paper, perhaps by introducing new technological alternatives which preserve some of the affordances of paper important for those processes, but perhaps by changing the processes themselves. Whatever is the case, the point needs to be made clear: without paper, organisations would be very different places than they are now.

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