Proceedings of the Third European Conference on Computer-Supported Cooperative Work
13-17 September, 1993, Milan, Italy
G. De Michelis, C. Simone and K. Schmidt (Editors)

The Use of Breakdown Analysis in Synchronous CSCW System Design

Silvia Pongutá Urquijo[1], Stephen A.R.Scrivener[2,1], Hilary K. Palmén[3]

[1] LUTCHI Research Centre, University of Loughborough, UK
[2] The Design Research Centre, University of Derby, UK
[3] Institute of Computer Based Learning, Heriot-Watt University, UK

Abstract: CSCW systems are invariably intended to support complex group activities. This complexity is reflected in the richness of the data required to adequately evaluate a system intended to support these activities. Consequently, there is a need for the development of an evaluation technique which can reliably provide diagnostic information quickly from rich data (such as video and audio recordings). In this paper, the development and use of an approach based on 'breakdowns' within the scope of a Model of Interaction is described. Breakdown analysis provides a systematic means of approaching large quantities of communication data, identifying those areas which highlight problems and relieving the evaluator of the task of consulting or becoming an expert in a more complex form of conversational analysis or HCI.

Introduction

The paradigm shift (Hughes *et al.*, 1991) from Human Computer Interaction to that which considers the group work, communication, social, political, and physical aspects within which a CSCW system is used presents numerous design and development problems. The traditional HCI system design approach of an iterative design cycle including both formative and summative evaluation activities is a valuable and potentially productive model. However, the particular methods used within this iterative design cycle to evaluate within a CSCW environment require development to accommodate the paradigm shift. This paper outlines the development of a practical approach to evaluation using the notion of "breakdowns" (Winograd and Flores, 1987). The potential of "breakdowns" in interaction and communication as an evaluation tool has been identified previously (Wright and Monk, 1989). However, the particular relevance of "breakdowns" to the evaluation of real-time CSCW systems is in the way they are produced naturally by users as part of the communication.

In the following section we introduce a set of studies of a prototype CSCW sketching tool for remote co-working (Clark and Scrivener, 1992). The data collection techniques employed in these studies were deliberately wide ranging. The users were video recorded, audio recorded, and detailed logfiles of their drawing activities were created. This approach to data collection produced a wealth of rich data. The problem facing the system developers was how to interpret this data in a meaningful manner that would provide information in a form suitable to direct system development. There are number of popular HCI methods which could provide the diagnostic information required by the system designers. However, given the particular relevance of 'breakdowns' to CSCW systems we developed and applied an analysis approach based on the detection and diagnosis of "breakdowns".

Background

Design at a Distance: The Loughborough-Adelaide Studies

The ROCOCO (RemOte COoperation and COmmunication) project investigated the communicational requirements of remotely sited designers working on a shared problem (Garner *et al.*, 1991; Scrivener *et al.*, 1993a). For the purposes of the project a system, called the ROCOCO STATION, was designed to enable geographically separated designer-pairs to communicate in real-time via an eye-to-eye video-link, a high-quality audio-link, and a shared drawing surface.

A central feature of the ROCOCO STATION is the ROCOCO SKETCHPAD, a computer-based Distributed Shared Drawing Surface (Clark and Scrivener, 1992) which allows persons sitting at different computer workstations to share a drawing surface. The surface takes the form of a large 'shared window' which is displayed on each workstation screen. Users have simultaneous access to the drawing surface (the ROCOCO SKETCHPAD). They are able to draw with a selection of "pen-types" and can point to existing drawings with a "telepointer". The drawing surface can, in principle, be shared by any number of users. The sketchpad is operated via a digitiser and pen. To one side of the workstation screen is a 'Video Tunnel' video-link (incorporating a video camera and monitor). This arrangement, developed by Smith *et al.* (1989), uses half silvered glass and mirrors to allow eye-to-eye contact to be made over the video-link. Users have a high-quality headset audio-link.

In the second phase of the project the communication requirements of group design were investigated in conditions where, typically, communication was impoverished. These experimental conditions were achieved by manipulating the features of the ROCOCO STATION. The four configurations shown in Table I were investigated. Scrivener *et al.* (1993a) found that real-time person-to-person interaction between designers engaged in the initial stages of design could be effectively mediated via a computer-based communications system comprising a shared drawing surface and an audio-link: the Video-off condition.

TABLE I: ROCOCO Workstation Experimental Configurations

Configuration	Sketchpad	Video tunnel	Audio link
1	on	on	on
2	on	on	off
3	**on**	**off**	**on**
4	on	off	off

During February 1992, remote design sessions were conducted between the LUTCHI Research Centre in Loughborough, England, and Flinders University in Adelaide, South Australia (a land distance of over 16 000 km). Using ISDN communications technology and a headset telephone, the Video-off configuration of the ROCOCO STATION was replicated between the two sites. That is, two designers were able to talk to each other via a telephonic link and draw together via the ROCOCO SKETCHPAD. This enabled an assessment of the configuration in a more commercially realistic form (i.e. using standard telecommunications infrastructure).

Four designers took part in this study: two final year BSc in Design and Technology students at Loughborough University of Technology, and two B.A. Industrial Design graduates of the University of South Australia. Each subject was assigned to a test pair. The tasks used in the study were chosen from those used in the ROCOCO project. In the course of the study each subject pair completed the same three design tasks. The six studies were carried out sequentially over a period of three days (i.e. two each day).

At the end of the first and last session each designer was asked to complete a questionnaire that consisted of statements relating to the fitness for the task and the usability of the system. The results obtained from the questionnaire were generally positive in both respects (for a discussion of the results see Scrivener *et al*, 1992 and Scrivener *et.al.*, 1993a, 1993b). However, it was obvious to observers of the studies that communication problems had arisen (for example, coordinating page changes) which were not captured explicitly in either the rated or open question sections of the questionnaire data. It was also obvious that these observed problems were ones that affected usability, and therefore had implications for the re-design of the system. Consequently we investigated methods for evaluating the performance of the system using the audio and video recordings taken during the design sessions.

Issues effecting evaluation approaches

There are numerous techniques that can be used as part of an evaluation approach. Popular research and evaluation methods would include the Interview, Usability Checklist, Focus group, Expert Walkthrough, Incident Diary, and Questionnaire. Each method has strengths and weaknesses which make it either appropriate or inappropriate depending on the resources available to the evaluation activity and the purpose of the system being evaluated. Rather than attempt to comprehensively list and describe the repertoire of techniques available this section intends to introduce some of the practical issues that should be considered when selecting an appropriate technique.

The general aim of an evaluation is to produce recommendations for design improvements. The evaluators have to consider issues such as time, finance, resource availability, the type and quantity of data produced, and the reliability and validity of the methods. These considerations include planning for when recommendations are required, how long, and when resources are available. The resources include users, equipment, money, and effort required (and available) to ensure that the evaluation can be completed. The quantity and type of data required is effected by the extent to which the task and environment are realistic. The evaluator needs to consider questions such as whether the evaluation can take place in the system's intended environment, what data is required, will descriptive information provide a sufficient basis for improvements, and can quantitative information be accurately interpreted?

The selection of evaluation techniques depends on the interaction of all these factors. Using more then one technique can help ensure that the findings are reliable. However, time, money, and resource availability often provide undesirable limitations and the pressure is on evaluators to provide quick, cheap, and effective feedback to the system developers. While an evaluation set in the intended system environment, with the intended user population, may provide the most appropriate data, the intended user population may not be available and the data gathered from a naturalistic study may prove too complex for a reliable interpretation.

CSCW systems are invariably intended to support complex group activities. This complexity is reflected in the richness of the data required to adequately evaluate a system intended to support these activities. Consequently, there is a need for the development of an evaluation technique which can provide reliable diagnostic information quickly from rich data (such as video and audio recordings). An approach based on 'breakdowns' has the potential to provide such a technique.

Breakdowns

Wright and Monk (1989) proposed a design evaluation method founded on two concepts:

1. **Critical incident**: defined as user behaviour which is suboptimal with respect to the functionality provided by the system and the intention of the users. A critical incident occurs in two situations: when the user backs up to some previous state after entering an undesired state, and secondly when the user makes redundant or ineffective actions. Critical incidents can be observed in video records, system logs or even contemporaneous observation.

2. **Breakdown**: defined as the moment when the user becomes conscious of the properties of the system and has to mentally break down or decompose his or her understanding of the system in order to rationalise the problem experienced. Winograd and Flores (1987) described the rationale for breakdowns as follows, " a computer is usable to the extent that it serves to fulfil a task in a 'transparent' fashion. Ideally, the user works without being aware of the system as a separate entity. Only in the case of 'breakdown', and the subsequent need for analytical interpretation of the artifact as possessing properties in its own right, does the system become part of the subjective experience of the interaction".

Wright and Monk (1989) studied a user working with a bibliographic data base for a total of ten hours. They considered four kinds of data: system logs from free use; system logs from the user performing set tasks, retrospective verbal protocol obtained during re-enactment of system logs and concurrent verbal protocol (or co-operative evaluation - i.e. the evaluator co-operates by verbalising during interaction).

Critical incidents were obtained from the first three kinds of data and breakdowns were obtained from the concurrent verbal protocol. They found that critical incidents and breakdowns together provided data that was very effective for system evaluation. They also noted that important problems were uncovered via breakdowns, and that the breakdowns were easier to detect than critical incidents. In conclusion, they advised the use of breakdowns because a critical incident is usually accompanied by a breakdown, but the converse is not necessarily the case.

In collaborative tasks the verbal discourse is unprompted. Participants are not compelled to "think aloud"; and if they do it is in order to cooperate with their partner, not an experimenter. Hence verbal protocols arising during collaboration between two or more people overcome the criticisms usually made of verbal protocols and in general should provide more reliable breakdowns in the sense that these will be reported for the benefit of those involved in the collaboration as a means of bringing the usability problems being experienced by the breakdown reporter into public awareness. It seemed to us, therefore, that Breakdown Analysis could be a useful tool for evaluating the performance of the ROCOCO SKETCHPAD in the Adelaide-Loughborough studies.

Usability Evaluation and CSCW

Evaluating the Usability of CSCW Systems

The importance of achieving usability in human-computer system design is well understood. Shackel (1981, 1991) argues that usability depends upon the design of the tool (i.e. the computer system) in relation to the users, the task, and the environment, and the success of the user support provided (e.g. training, manuals, and other job aids). Each components has its own characteristics which influence the interaction between the user and the computer or, as is becoming increasingly common, between several users and one or more software applications (Benyon *et al.*, 1990). In general, a breakdown in human-computer interaction is an indicator of usability failure. The decomposition of a system in terms of its four principal components (Task, User, Tool and Environment, TUTE) provides a framework for usability evaluation.

A synchronous-remote CSCW system, such as the ROCOCO SKETCHPAD (Clark and Scrivener, 1992), designed to support two or more users working in real-time collaboration can be visualised as a system composed of two (or more) connected human-computer sub-systems. In order to evaluate such a system in terms of TUTE interactions the model must be extended to take these multiple sub-systems into account. In Figure 1 each sub-system is decomposed in terms of it's four principal components, where the boundary separating two components represents a relationship or interface between them, as do the vectors connecting two components. Decomposed in this way, each system can be evaluated independently.

However, when connected for CSCW, as in Figure 1, the evaluation must consider the new relationships in the Model of Interaction between human-computer sub-systems. In Figure 1, which represents two connected sub-systems A and B, the two additional direct relationships are shown that link the sub-systems via connections between User A and User B, and Tool A and Tool B. The Loughborough-Adelaide system fits this model, being composed of different users and instances of the same class of tool replicated in different physical environments.

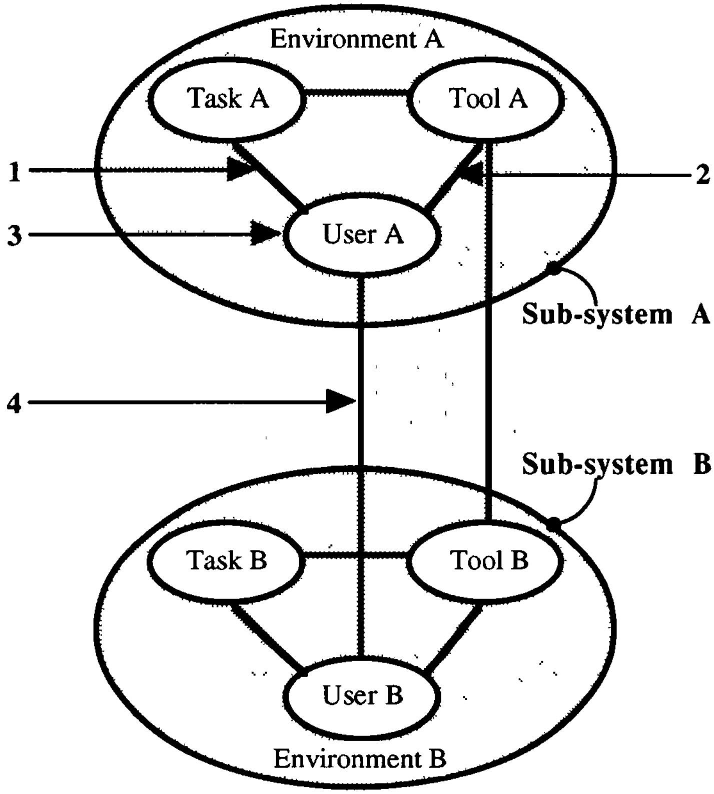

Figure 1 Interaction between Two Human-Computer Sub-Systems

The Role of the Model of Interaction in Breakdown Analysis

In the Breakdown Analysis method described below the Model of Interaction is used as a basis for classifying breakdowns. The aim of the classification is not to put a breakdown event into a neat slot, but to enhance the quality of the information regarding the breakdown such that it is likely to more readily assist the evaluator in identifying its underlying cause (Booth,1990).

Given the definition provided in the previous section, a breakdown occurs between the user and some element of the system with which he or she is interacting. From Figure 1 (see labelled vectors 1,2,3,and 4) it is clear that the user is directly involved in four primary interactions each of which can be subject to breakdown. These interaction are between:

1. **User and task**: where a breakdown can occur when the user has difficulties understanding the task or does not have the necessary knowledge to accomplish the objectives set by the task.

2. **User and tool**: breakdowns here are related to the two elements that compose a tool: the hardware and software interfaces. Two kinds of problems may occur involving either or both elements. These are tool failure, where a technical problem occurs, and user-tool mismatch, where the user does not understand the tool.

3. **User and environment**: where a breakdown occurs when the user becomes conscious of some intrusive property of the environment.

4. **User and user**: here the breakdowns are usually breakdowns in communication. This class of breakdown is elaborated in some detail below.

In the Loughborough-Adelaide studies users communicated via the audio link and the ROCOCO SKETCHPAD. A number of different types of communication breakdown were noted:

4.1 Sufficiency: a sufficiency breakdown occurs when the information provided to a partner is not sufficient for understanding the sender's intention.

4.2 Clarity: a breakdown in clarity occurs when a message is inaudible or illegible, for example poor handwriting.

4.3 Comprehension: a breakdown of this kind occurs when, for example, cultural differences lead to failures of comprehension, such as when one partner refers to religious practices that are alien to the other.

4.4 Attention: a breakdown of attention occurs when the receiver is either absorbed in the task or because some external distraction causes attention loss at a conversationally disruptive moment.

4.5 Coordination: a coordination breakdown occurs when users fail to coordinate their utterances, and consequently interrupt one another.

4.6 Feedback: this class of breakdown occurs when the source does not receive any acknowledgement from the receiver.

Figure 2 shows the full breakdown classification hierarchy together with the corresponding code of each category used during breakdown analysis.

Breakdown Analysis

In this section an evaluation method based on Breakdown Analysis is proposed for use as a part of an iterative system development process.

The method we propose consists of three stages:

Stage 1: Transcription and categorisation of breakdowns.
Stage 2: Causal diagnosis.
Stage 3: Remedy prescription

Using a medical analogy, if we regard a breakdown as the pathology of a system ailment, these stages correspond to the identification of symptoms, diagnosis, and the prescription of a method of treatment. In the following sections we describe and illustrate, using examples from the Loughborough-Adelaide study, each stage of the method.

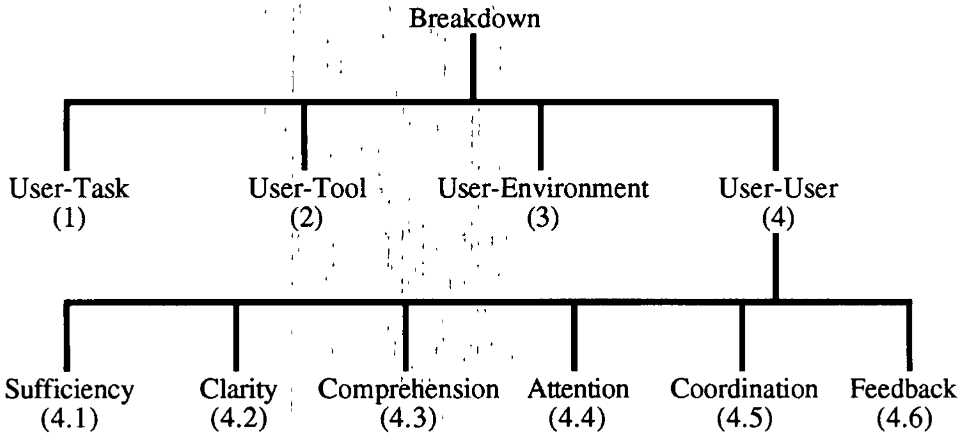

Figure 2. Classification of Breakdowns

Stage 1: Transcription and Categorisation of Breakdowns

The transcription and coding of breakdowns is concerned with the identification of the fact of a breakdown rather than its cause. This stage involves three steps: detection, transcription, and category assignment. Step 1, detection, can be done in two ways: by observation of video-recordings of the user-system interaction, or by direct observation of system use. The rule of thumb in breakdown detection is to record any instance where users' comments indicate self-awareness of user-system interaction, for example:

Subject 1 My pen does not want to work. I can not write anything

In Step 2, the breakdown detected in Step 1 is transcribed. The following data is recorded for each breakdown: time of occurrence, the subject(s) experiencing the breakdown, the sequence of utterances bounding the breakdown, and any comments about the context of the breakdown. The following example illustrates a transcribed breakdown.

Breakdown Analysis				
Experiment: Study 1 Pair 1			Date: July 1992	
Time	Subject	Occurrence	Code	Notes
25:28	OZ	What does it say?		Pointing at writing
	UK	Good question I've forgotten 'domestic'. It says domestic		
	OZ	Oh!! domestic		

In Step 3 the breakdown definitions associated with the Model of Interaction are used to categorise the transcribed breakdown, which is then assigned a category label. We will illustrate this process using the earlier example. Here subjects are experiencing a breakdown in communication clarity because subject OZ cannot read subject UK's writing, hence the breakdown is assigned the code 4, for communication, and (/)2, for clarity.

Breakdown Analysis				
Experiment: Study 1 Pair 1			Date: July 1992	
Time	Subject	Occurrence	Code	Notes
25:28	OZ UK OZ	What does it say? Good question I've forgotten 'domestic'. It says domestic Oh!! domestic	4/2	Pointing at writing in screen

Stage 2: Causal Diagnosis

So far the fact of a breakdown has been established and coded in terms of the Model of Interaction, however no attempt has yet been made to establish the cause of the breakdown. Hence, the objective of Stage 2 is to establish the underlying causes of the breakdowns documented in Stage 1. Stage 2 takes place once all the breakdowns observed during the analysis have been identified and classified. The crucial question addressed for each breakdown at this stage is "What is causing the breakdowns?"

Consider, for instance, the earlier example of breakdown in communication clarity. A number of plausible explanations can be postulated in this case. First, it may simply be that subject UK's handwriting is illegible. Alternatively, it may be that the UK workstation doesn't adequately support handwriting (for example, the stylus sampling rate might be too slow for effective scribing). Finally, it could be that the interaction between the two sub-systems (i.e. the communication between tools) may be affecting the user-subsystem interactions. Clearly, this example illustrates the point that the cause of a problem may not always be easy to identify, and further studies and tests may be required in order to isolate the specific cause or causes of a given breakdown.

In this case, it turned out that the breakdown in communication clarity could be attributed to the stylus sampling rate which was not fast enough for effective scribing. This conclusion was reached by looking at the set of communication clarity breakdowns as a whole which revealed that the problem was not isolated to one individual or one pair. In fact all subjects produced illegible script, thus suggesting a problem with the tool. This example demonstrates that the grouping of breakdowns in categories is of assistance to the analyst.

Stage 3: Remedy Prescription

In this the final stage, the information obtained from the previous stages, especially information regarding the cause(s) of each breakdown, is used as a basis for remedies to overcome the observed problems associated with the current system.

Distribution of Breakdowns: Session 3 of the Adelaide-Loughborough Study

We have applied the Breakdown Analysis method described above to the data generated in last session of each pairing in the Adelaide-Loughborough study (having evolved the method via analysis of the first and second sessions). Figure 3 represents the number of breakdowns per category experienced by each pair in Session 3.

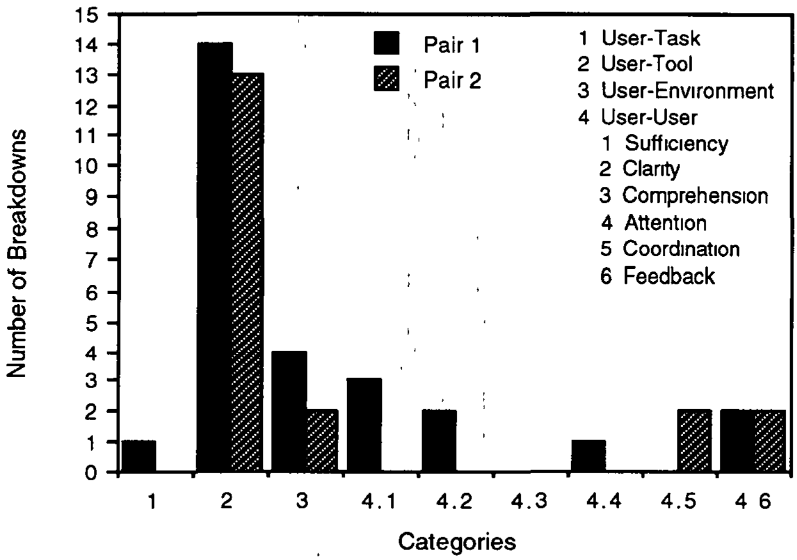

Figure 3 Number of Breakdowns per Category for each Pair

From the graphs it would appear that most of the breakdowns experienced occurred between the user and the tool. On analysis, the breakdowns were found to be caused either because the users had expectations that the tool couldn't support (e.g. freehand writing and sketching) or because of operating performance (eg. inadequate response time).

In the third session the subjects experienced fewer breakdowns in communication than in the previous two studies. One reason for this could be that they developed conventions to avoid certain difficulties. For example, a convention that both pairs adopted was to agree page changes before actually executing them, thus avoiding many of the breakdowns in communication coordination that occured when pages were unilaterally changed.

As users became more familiar with the system their awareness of the environment increased and more breakdowns of this type were reported (as compared to earlier sessions). For example, in the final session subjects discussed matters such as the headset comfort and environmental noises (one subject commented that he could hear a motorcycle going by at his partners end, and in another instance a UK subject commented that he could hear the noise of the marks being made on the board by his partner).

Conclusions

Some of the advantages obtained from analysing breakdowns within the scope of the Model for Interaction are:

1. The Model for Interaction provides the means to focus on the most important aspects of the user-system interaction.
2. Breakdown analysis uncovers problems that users actually register.
3. The focus on users yields insight into how the system is perceived and whether the user finds the system usable or not.
4. Breakdown analysis, by focussing on those parts of the system (i.e user, tool, task, environment) where the user is experiencing breakdowns, isolates areas in need of refinement.
5. By identifying the areas where the user is experiencing difficulties, breakdown analysis can give some indication of how to solve usability problems.

On a more general level breakdown analysis provides a systematic means of approaching large quantities of communication data. The benefits of the approach lie in that each breakdown provides information that indicates a problem with a prototype. Consequently it is not necessary to count each breakdown and use extensive resources analysing vast quantities of data. As it is not necessary to count the occurrences of breakdowns it is also not necessary to pilot the system with a large number of users. While the breakdowns themselves do not necessarily include much interpretive data obtaining this, once a problem has been identified, is a simple matter via querying the original communicants.

The approach provides quick feedback to the system designers - facilitating rapid prototyping. While the lack of interpretative information can be considered a short coming of the approach its important features are that it quickly identifies problem areas, and can handle large quantities of data effectively. Ultimately, it is up to the individual system development team to decide how to use this approach. Breakdowns could be used late in the design cycle, when the prototype has been delivered, to check whether there are still improvements required. Alternatively the approach could be used early in the design cycle for rapid prototyping. We have focussed on the breakdowns in user-system interaction in CSCW systems. However, studies of failures in networking (Rogers, 1992) and the use of shared drawing tutorial system (Sharples, 1992) suggest that the analysis of "breakdowns" may be generally applicable to the socio-technical system as a whole.

It is probable that the type and frequency of breakdowns varies at different areas in the prototype development; this is an area that may benefit from further research. Given the above point, it is highly likely that breakdowns will continue to occur even when the system is delivered and running since breakdowns may not be uncovered because of time and cost limits on the number of design iterations possible. Also differences between the environments and users involved in the evaluation and those of the workplaces into which the system is installed may also be reflected in new breakdowns. However, it is our belief that many on the primary technical, communication, and interaction inadequacies of a system that impact on usability can be uncovered using breakdown analysis. If resources are available the system can be modified to repair for system-in-operation breakdowns.

In the absence of such resources users are obliged to evolve recovery and repair strategies which, whilst not enhancing the systems usability, increase its efficiency and usefulness. It may be that breakdown analysis can be employed in the workplace to aid the development of effective repair and recovery strategies by making explicit to users the nature of the problems encountered; again this is any area worthy of further research.

When planning the evaluation activities for an iterative system development cycle the use of breakdown analysis has the potential to be cost effective because it can:

- handle large amounts of data (eg video recordings)
- provide development feedback with limited user time.
- provide effective feedback using limited evaluator/specialist time (coding activities are quicker than formal methods such as speech act coding).
- be effective when there is limited availability of equipment (minimum of two workstations required).
- provide quick feedback to the developers.

Breakdown analysis provides a means of systematically identifying those areas which highlight problems and relieves the evaluator of the task of consulting or becoming an expert in more complex forms of conversational analysis (eg Heath and Luff, 1991). It does not require an HCI specialist to use this technique, merely familiarisation with the notion of breakdowns.

Acknowledgements

At the time this work was carried out Scrivener was a member of staff at Loughborough University of Technology. The authors would like to thank Sean Clark (LUTCHI Research Centre, Loughborough University, UK) for his advice and assistance during the study, and to the anonymous referees of the paper for their comments.

References

Benyon, D., Rogers, Y.R. and Preece, J. (1990): *A Guide to Usability*, The Open University, Milton Keynes.

Booth, P.A. (1990): "ECM: A Scheme for Analysing User-System Errors", *Human-Computer Interaction-INTERACT'90*, in D. Diaper *et al.* (eds.), Elsevier Science Publishers, North-Holland, 1990, pp 47-54.

Clark, S.M. and Scrivener, S.A.R. (1992) "The ROCOCO Sketchpad Distributed Shared Drawing Surface", LUTCHI Report No. 92/C/LUTCHI/0150, LUTCHI Research Centre, University of Technology, Loughborough, UK.

Garner, S.W., Clarke, A.A., Scrivener, S.A.R., Clark, S., Connolly, J., Palmén, H., Schappo, A., Smyth, M. (1991): "The Use of Design Activity for Research into Computer Supported Co-operative Working", *Proceedings of DATER'91*, Loughborough University, UK.

Heath, C., and Luff, P. (1991): "CSCW: Collaborative activity and Technological design: Task co-ordination in London Underground control rooms", in L. Bannon, M. Robinson & K. Schmidt (eds) *Proceedings of the Second European Conference on Computer-Supported Cooperative Work,* Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 65-80.

Hughes, J., Randall, D. and Shapiro, D. (1991): "CSCW: Discipline or Paradigm? A sociological Perspective", in L. Bannon, M. Robinson & K. Schmidt (eds) *Proceedings of the Second European Conference on Computer-Supported Cooperative Work,* Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 325-336.

Rogers, Y.R. (1992): "Ghosts in the Network: distributed troubleshooting in a shared working environment", in J. Turner & R. Kraut (eds) *Proceedings of CSCW 1992 : Sharing Perspectives*, ACM, New York, USA, pp 346-355.

Scrivener, S.A.R., Harris, D., Clark, S.M., Rockoff,T., and Smyth, M.(1992): "Designing at a Distance: Experiments in Remote-Sychronous Design", *Proceedings of OZCHI'92: CHISIG Annual Conference* , Gold Coast, Australia, November 1992, pp 44-53.

Scrivener, S.A.R., Clark, S., Clarke, A., Connolly, J., Garner, S., Palmen, H., Smyth, M., Schappo, A. (1993a): "Real-Time Communication between Dispersed Work Groups via Speech and Drawing",*Wirschaftsinformatik*, No 25, Vol. 2, pp 149-156.

Scrivener, S.A.R., Harris, D., Clark, S.M., Rockoff,T., and Smyth, M. (1993b): "Designing at a Distance via Real-Time Designer-to-Designer Interaction", *Design Studies*, (accepted for publication).

Shackel, B.(1981): "The Concept of Usability", in J.L. Bennett, D. Case, J. Sandelin and M. Smith (eds.), *Visual Display Terminals: Usability Issues and Health Concerns*, Englewood Cliffs, NJ Prentice Hall, pp 45-88.

Shackel, B. (1991): "Usability-Context, Framework, Definition, Design and Evaluation", in B.Shackel & S.Richardson (eds.), *Human Factors for Informatics Usability*, Cambridge University Press.

Sharples, M. (1993): "A Study of Breakdowns and Repairs in a Computer Managed Communication System", *Interacting with Computers*, (accepted for publication).

Smith, R.B, O'Shea, T., O'Malley, C., Scanlon, E., Taylor, J. (1989): "Preliminary Experiments with a Distributed Multi-media Problem Solving Environment", *Proceedings of the First European Conference on Computer-Supported Cooperative Work,* September, London,UK, pp. 19-34.

Winograd T. & Flores F. (1987.) *Understanding Computers and Cognition: A New Foundation*, Ablex, Norwood, NJ, USA.

Wright P.C. & Monk A.F. (1991): "A Cost-Effective Evaluation Method for Use by Designers", *International Journal of Man-Machine Studies*, 35, pp. 891-912.

Wright, P.C. & Monk, A.F. (1989): "Evaluation for Design", in A. Sutcliffe, & L. Macaulay (eds.) *People and Computers* V, Cambridge University Press, Cambridge, UK, pp 345-358.