COMIC

ESPRIT BASIC RESEARCH PROJECT 6225

Social Mechanisms of Interaction

Abstract

The present report documents the research activities undertaken in Task 3.1 of the COMIC project.

The objective of the three years of research of Strand 3 is to develop a conceptual foundation for designing computational mechanisms of interaction for CSCW applications that can support the complex task of articulating distributed cooperative activities.

The present deliverable presents analyses of a number of real-world mechanisms of interaction. In doing that, the deliverable focuses on the features of these mechanisms that enable them to provide efficient and flexible support of coordination of distributed activities and the way these mechanisms are managed cooperatively. On the other hand, based on these and other studies, the deliverable presents and discusses a conceptual framework for analysis of mechanisms of interaction and derives a set of requirements for a notation for constructing computational mechanisms of interaction

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Project coordinator:

Tom Rodden
Computing Department
University of Lancaster
Lancaster LA1 4YR
United Kingdom
Phone: (+44) 1524 593 823
Fax: (+44) 1524 593 608
Email: tom@comp.lancs.ac.uk

The COMIC project comprises the following institutions:

Gesellschaft für Mathematik und Datenverarbeitung (GMD), Bonn, Germany
Risø National Laboratory, Roskilde, Denmark
Royal Institute of Technology (KTH), Stockholm, Sweden
Swedish Institute for Computer Science (SICS), Stockholm, Sweden
Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
University of Amsterdam, Amsterdam, The Netherlands
University of Lancaster, Lancaster, United Kingdom (Coordinating Partner)
University of Manchester, Manchester, United Kingdom
University of Milano, Milano, Italy
University of Nottingham, Nottingham, United Kingdom
University of Oulu, Oulu, Finland

Editor of this report:

Kjeld Schmidt
Cognitive Systems Group
Risoe National Laboratory
P.O. Box 49
DK-4000 Roskilde, Denmark
Phone: (+45) 4677 5146
Fax: (+45) 4675 5170
Email: kschmidt@risoe.dk

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Introduction

The present report documents the research activities that have been conducted within Task 3.1 of the COMIC project.

The objective of the three years of research of Strand 3 is to develop a conceptual foundation for designing computational mechanisms of interaction incorporated in CSCW applications in order to support the articulation of cooperative work. Or in the words of the Technical Annex of the COMIC project:

> "The overriding objective of this workpackage is to achieve a clear understanding of the role of mechanisms of interaction in cooperative work and the requirements they must meet in terms of visibility, flexibility, etc. so as to determine the role and requirements of computational notations as means for incorporating mechanisms of interaction in CSCW applications. Based on the results of that research, computational notations for incorporating mechanisms of interaction in CSCW applications will be developed and tried out experimentally." (COMIC, 1992, p. 41).

More specifically, the objectives of Task 3.1 have been:

> "to investigate social mechanisms of interaction in coordination and cooperation from a social science perspective, so as to identify requirements for computational notations of mechanisms of interaction in CSCW applications" (COMIC, 1992, p. 43).

In the course of the research within Task 3.1, a number of interlaced activities have been undertaken:

(1) Comparative analysis. A comparative analysis of empirical field study cases has been accomplished. The purpose of that investigation is, in general, on the basis of available social science evidence, to develop a conceptual framework of cooperative work and its articulation that can deepen our understanding of articulation work and, in particular, to explore and develop the hypothesis of 'mechanisms of interaction' with a view to deriving design requirements from the way in which symbolic artifacts are used for articulating cooperative activities in real world settings.

The initial results of this work was presented in an internal report from Task 3.1 from February 1993 (COMIC-Risø-3-3) entitled "Modes and Mechanisms of Interaction in Cooperative Work". A revised version of this report was included as Part 1 of Deliverable 3.1 (Simone and Schmidt, 1993) as "a preview" of the present deliverable in order to make the conceptual foundation of the concurrent research in Task 3.2, as reported in Part 2 and 3 of Deliverable 3.1, more accessible to readers.

(2) Field studies of mechanisms of interaction. A number of new field studies of the use of symbolic artifacts for coordination purposes in different real-world settings have been conducted: software design and testing (Carstensen, 1994; Carstensen et al., 1994), engineering design and process planning in manufacturing (Carstensen and Sørensen, 1994a; Pycock and Sharrock, 1994; Sørensen, 1994b; Sørensen, 1994c; Sørensen, 1994a; Borstrøm et al., 1995), and production and distribution of technical documentation in manufacturing (Andersen, 1994a; Andersen, 1994b).

In these field studies, the concept of mechanism of interaction as well as the model of objects of articulation work, as defined in COMIC Deliverable 3.1 from September 1993, have been applied systematically as experimental means for conceptualizing and modelling findings in order to put these constructs to test. The experience from using the concept of mechanism of interaction and the model of objects of articulation work in the field studies indicated some conceptual inconsistencies in the definition of mechanism of interaction as well as in the model. The definition of mechanism of interaction and the model was revised and developed accordingly, in several steps, from April to August 1994 (Schmidt and Simone, 1994). The essence of the of the development is that a mechanism of interaction is conceived of, not as *an artifact with certain characteristics*, but as a *protocol that is embodied in an artifact*.

(3) Theoretical reexaminations. The very idea of artifacts stipulating the articulation of cooperative activities, that underlies the concept of mechanisms of interaction, may be controversial from the perspective of some traditions in the social sciences. In view of this, the concept of mechanism of interaction has been re-examined in light of the alternative theoretical positions and the evidence produced by these positions. The theoretical reconsideration is reported in the three chapters constituting Part 1 of this deliverable.

(4) MOI analysis and design cycle. Based on the field study findings, the entire process of requirements analysis, requirements specification and conceptual design of a computational mechanism of interaction has been performed as an experiment (the bug report form, cf. Carstensen and Sørensen, 1994b), and it has been demonstrated that the notation can construct such a mechanism (cf. Simone et al., 1994).

(5) Recursiveness explored. The field studies has provided a first empirical basis for addressing the issue of linking computational mechanisms of interaction. With the field study findings as a basis, the issue of recursiveness (in the sense that one mechanism can constrain the behavior of another mechanism in some way) has been developed and brought to the fore in the design of the notation, e.g., in the form of *policies*.

At the same time, the notion of linking mechanisms of interaction provides what seems to be a very useful approach to exploring the relationship between the concept of mechanism of interact (as investigated in Strand 3) and the concept of organizational context (as investigated in Strand 1). Our proposition is that a computational representation of organizational context can usefully be conceived of as identical to a system of linkable computational mechanisms of interaction. This proposition has been discussed on the basis of field study results and has been corroborated (Schmidt et al., 1994).

Progress and results

Altogether, the work in Strand 3 has been conducted as an ongoing and highly stimulating interaction between social science and computer science perspectives. The ensuing results of the research within Task 3.1 can be summarized as follows:

(1) Conceptual framework. A conceptual framework has been developed for conceptualizing the requirements of computational mechanisms of interaction in a systematic way as well as for designing and evaluating computational mechanisms of interaction. According to this framework, a computational mechanism of interaction should be conceived of as an abstract device incorporated in a software application so as to support the articulation of the distributed activities of multiple actors with respect to that application and the field of work it represents.

The concept of mechanism of interaction has been put to test by being used as a framework for in-depth field studies of the use of symbolic artifacts for articulating distributed activities in cooperative work settings. The overall result is that it is operational, leads to interesting results, and is useful as a framework for requirements analysis with a view to designing computational mechanisms of interaction.

(2) Definition of mechanisms of interaction. As a result of the experience from applying the concept in field studies, a more operational definition of the concept of mechanism of interaction has been developed.

In COMIC Deliverable 3.1, the concept of mechanisms of interaction was defined as follows:

> "A mechanism of interaction can be defined as a device for reducing the complexity of articulating distributed activities of large cooperative ensembles by stipulating and mediating the articulation of the distributed activities." (Simone and Schmidt, 1993, p. 6)

This initial definition has been shown to create certain problems. In fact, when applying this definition to the various artifacts used for articulation work in the cooperative work settings that have been investigated, none of the artifacts qualified as mechanisms of interaction according to the definition, perhaps with the exception of the kanban system. The problem is that the initial definition defined a mechanism of interaction as an artifact with a certain function and certain concomitant characteristics and that the artifacts that were analyzed, and probably all conventional paper-, cardboard-, and plastic-based artifacts used for these purposes, rely heavily on human actors to enact the procedures and conventions as well as to take the inherently inert artifact through all state changes. In other words, the initial definition presumed a specific allocation of functionality between human actor and artifact, in the form of activeness on the part of the artifact, that can only be realized by computational mechanisms of interaction. Even in the case of the kanban system, which comes very close to an allocation of functionality in which the artifact is experienced as *actively* stipulating and mediating articulation work, all state changes to the system requires human intervention for every tiny step (taking the card, reading it, interpreting it, sending it to the correct work station etc.).

As a definition of computational mechanisms of interaction, the initial definition has proved quite adequate, witness the comparative analysis of existing CSCW systems in Part 3 of Deliverable 3.1. (Simone and Schmidt, 1993).

The problem arises because we want the concept to be applicable to requirements analysis, with a view to identifying likely candidates for computational mechanisms of interaction, as well as to the design of such computational mechanisms of interaction. Thus, since the allocation of functionality between human actor and artifact will change, perhaps radically, as a result of incorporating mechanisms of interaction in computer systems, the definition should not presume a specific allocation of functionality. To the contrary, it should span the entire range of allocation of functionality and hence of local control.

Instead of the initial definition, we have therefore adopted the following:

> A mechanism of interaction can be defined as a protocol, encompassing a set of explicit conventions and prescribed procedures and supported by a symbolic artifact with a standardized format, that stipulates and mediates the articulation of distributed activities so as to reduce the complexity of articulating distributed activities of large cooperative ensembles. Similarly, a computational mechanism of interaction is defined as a computer artifact that incorporates aspects of the protocol of a mechanism of interaction so that changes to the state of the mechanism induced by one actor can be automatically conveyed by the artifact to other actors in an appropriate form as stipulated by the protocol. (Schmidt and Simone, 1994)

With this definition, social and computational mechanisms of interaction are not conceived of as different kinds of mechanisms. To the contrary, all mechanisms of interaction are fundamentally and inexorably “social” mechanisms of interaction in that they are constituted by a set of procedures and conventions and supported by “a symbolic artifact with a standardized format”. The adjective ‘social’ is redundant. Accordingly, computational mechanisms of interaction are conceived of as a special category of mechanisms of interaction that is characterized by a specific allocation of functionality between human actors and artifact.

(3) Requirements of mechanisms of interaction. The requirements to be satisfied by computational mechanisms of interaction, as identified in COMIC Deliverable 3.1 from September 1993 (Simone and Schmidt, 1993) have been reconsidered and revised in the light of the field study experiences, the effort to model mechanisms of interaction, and the experimental conceptual design of a computational mechanism of interaction. The following developments are the most important:

(a) In order to allow for implicit understanding of certain aspects of articulation work, incomplete and not-yet complete specification, and in order not to force actors to explicitly specify a mechanism of interaction to a larger degree than deemed necessary, the notation should provide means for handling incomplete definitions of attributes.

(b) Since no single mechanism will apply to all aspects of articulation work in all domains of work, the computational mechanism of interaction must provide means for establishing links with other computational mechanisms of interaction embedded in other applications in a wider organizational field and thereby provide means for developing composite mechanisms of interaction in a bottom-up fashion.

(c) Since, according to the fundamental propositions of the conceptual framework of developed in Strand 3, articulation work is infinitely recursive in the sense that one cooperative work arrangement can take another cooperative work arrangements as its field of work and so forth, this fundamental recursiveness should be reflected in the notation. The notion of linkable computational mechanisms of interaction has been developed to provide for this.

(4) Model of Articulation work. A 'prototype' model of the 'objects and operations' of articulation work has been developed in order to provide a preliminary basis for developing the γ-level of the notation. In relation to the tentative model presented in Deliverable 3.1, the major advances have been made several respects: (a) a distinction between two statuses of articulation work, nominal and actual, has been introduced, especially to clarify the different statuses of resources in the model; (b) the status of the field of work in the model has been clarified in that resources-in-use (apart from human resources, of course) are now taken to belong to the field of work; and (c) conceptual structures has been given a more prominent and consistent role in the model.

Structure of the deliverable

The deliverable presents the results of this work. On the one hand the deliverable presents an analysis of a number of real-world mechanisms of interaction. In doing that, the deliverable focuses on the features of these mechanisms that enable them to provide efficient and flexible support of coordination of distributed activities and the way these mechanisms are managed cooperatively. On the other hand, based on these and other studies, the deliverable presents and discusses a conceptual framework for analysis of mechanisms of interaction and derives a set of requirements for a notation for constructing computational mechanisms of interaction.

Reflecting the dual objectives of the work in Task 3.1, Deliverable 3.2 is divided into two parts:

Part 1 presents and discusses complementary contributions to the conceptual framework for analysis and design of mechanisms of interaction.

Chapter 1.1 presents a reworked version of the theoretical framework for analysis and design of mechanisms of interaction that was presented, ahead of schedule and as a preview, in COMIC Deliverable 3.1 in September 1993. The paper discusses the concept of mechanisms of interaction in relation to alternative theoretical perspectives.

Chapter 1.2 re-examines a case study in terms of concepts drawn from the literature on technologies of representation. By drawing on concepts from this literature, the paper provides a number of inputs to the developing notion of mechanism of interaction

Chapter 1.3 suggests some ways in which the study of mechanisms of interaction may be informed by the employment of the ‘performative’ approach to organization as developed in Strand 1.

Part 2 presents findings from new field studies of mechanisms of interaction undertaken in the course the COMIC project:

Chapter 2.1 presents an analysis of the construction note.

Chapter 2.2 presents an analysis of the bug report form.

Chapter 2.3 presents an analysis of the augmented bill of materials.

Chapter 2.4 presents an analysis of the CEDAC board.

Chapter 2.5 presents an analysis of the product classification scheme.

Chapter 2.6 presents an analysis of the fault report form.

The appendix gives background information on the ‘Foss Electric’ field study from which the analyses of the mechanisms of interaction described in chapter 2.2-2.5 are drawn.

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Part 1

Mechanisms of interaction — Conceptual framework

Mechanisms of interaction reconsidered

Kjeld Schmidt

Risø National Laboratory

Preface

The concept of mechanisms of interaction is an evolving construction. The present paper is thus to be read as a reexamination of the concept as presented in COMIC Deliverable 3.1 from September 1993 (Schmidt, 1993).

The concept has been reexamined in the light of challenges from several sides:

First, a number of new field studies of the use of symbolic artifacts for coordination purposes in different real-world settings have been conducted: software design and testing (Carstensen, 1994; Carstensen et al., 1994), engineering design and process planning in manufacturing (Carstensen and Sørensen, 1994; Pycock and Sharrock, 1994; Sørensen, 1994b; Sørensen, 1994c; Sørensen, 1994a; Borstrøm et al., 1995), and production and distribution of technical documentation in manufacturing (Andersen, 1994a; Andersen, 1994b). In these field studies, the concept of mechanism of interaction was applied experimentally as a framework for conceptualizing and modelling empirical findings, and the experience gained from these studies indicated some conceptual inconsistencies in the definition of mechanism of interaction as well as in the model of articulation work. As a result, these constructs have been revised accordingly and developed further.

Second, the very idea of *artifacts that stipulate* the articulation of cooperative activities, that underlies the concept of mechanisms of interaction, is controversial from the perspective of certain traditions in the social sciences. In view of this, the concept of mechanism of interaction has been reexamined in light of the alternative theoretical positions and the evidence produced by these positions.

Third, in the course of deriving requirements for the ongoing development of the notation for computational mechanisms of interaction in COMIC Task 3.2 and 3.3, a number of issues have been raised that have made it imperative to reconsider fundamental assumptions, e.g., the relationship between the protocol of the mechanism and the artifact in which the protocol is embodied; the provision of a model of objects and functions of articulation work as a basis for the ‘baskets’ of the γ-level of the notation; the connections between a mechanism of interaction and the field of work.

And fourth, the initial explorations of the relationship between the concept of malleable and linkable mechanisms of interaction and the concept of representations of organizational context indicate that a computational representation of organizational context can usefully be conceived of as identical to a system of linkable computational mechanisms of interaction (Schmidt et al., 1994).

Thus, while the present paper was originally intended to be an updated version of the paper on “Modes and mechanisms of interaction” from September 1993,[1] it is in important respects a thoroughly transformed exposition of the concept of mechanisms of interaction. More specifically, the introductory sections on cooperative work and modes of interaction (section 2 and 3) are revised versions of similar sections in the September 1993 version, whereas the rest of the paper (section 4) have been written from scratch with only minor overlaps.

The structure of the exposition has been changed in an important respect: the case studies are no longer given in ‘batch mode’ in a separate section but are discussed at relevant points in the theoretical discourse.

1. Introduction

In the design of conventional computer-based systems for work settings the core issues have been to develop effective computational models of pertinent structures and processes in the field of work (data flows, conceptual schemes, knowledge representations) and adequate modes of presenting and accessing these structures and processes (user interface, functionality).[2] While these systems, more often than not, were used in cooperative work settings and even, as in the case of systems that are part of the organizational infrastructure, were used by multiple users (e.g., database systems), the issue of *supporting the articulation of cooperative work by means of such systems* has not been addressed directly and systematically, as an issue in its own right. If the underlying model of the structures and processes in the field of work was ‘valid’, it was assumed that the articulation of the distributed activities was managed ‘somehow’. It was certainly not a problem for the designer or the analyst.[3]

Consider, for example, the booking system of an airline. It is a computer-based system for the cooperative task of handling reservations. The database of the booking system embodies a model of the seating arrangements of the different flights. Taken together, the seating arrangements and the database model constitute what we can call the common field of work of the booking agents. Thus, the operators of the booking agencies cooperate by changing the state of the field of work, in casu, by reserving seats. Apart from providing a rudimentary access control facility, the booking system does not in any way support the coordination

1 The paper entitled “Modes and Mechanisms of Interaction in Cooperative Work” was included as Part 1 of Deliverable 3.1 as “a preview” of the present deliverable in order to make the conceptual foundation of the research in Task 3.2, as reported in Part 2 and 3 of Deliverable 3.1, accessible to readers.

2 Cf. Jackson: “Our concern in JSD is to ensure that the system correctly reflects the real world as it is, and to provide the functions requested by the user, to a specification in which the user has the determining voice.” (Jackson, 1983, p. x)

3 A similar point was made very early in CSCW by Anatol Holt: “Whatever has to do with task inter-dependence — *coordination* — is left to the users to manage as best they can, by means of shared databases, telephone calls, electronic mail, files to which multiple users have access, or whatever ad hoc means will serve.” (Holt, 1985).

and integration of the interdependent activities of the operators. In this case, however, the field of work can be handled as a system of discrete and extremely simple (binary) state changes. Apart from the fact that a seat can only be assigned to one person at a time, there are no interactions between processes. Accordingly, even though a booking system does not support articulation work, it is seemingly quite sufficient for the job. However, some if not most cooperative work arrangements in modern industrial societies are faced with fields of work that are far more complex in terms of number of interacting processes and states, irreversibility, concurrency, uncertainty, and so forth. Since such ensembles therefore are faced with more complex interdependencies between individual activities, they cannot rely on accomplishing their cooperative effort merely by changing the state of the field of work; such arrangements must articulate the distributed activities of their members by other means.

CSCW can be conceived of as an endeavor to understand the nature and support requirements of cooperative work arrangements with the objective of designing computer-based technologies for such arrangements (Schmidt and Bannon, 1992). Thus, in order to be able to conceptualize and specify the support requirements of cooperative work we need to make a fundamental analytical distinction between (a) *cooperative work*: interdependent work activities carried out in relation to a common field of work and mediated by changes to the state of the field of work, and (b) *articulation work*: activities arising from the fact that the work requires and involves multiple agents whose individual activities need to be coordinated, scheduled, meshed, integrated etc., in short, articulated. This distinction is fundamental to CSCW and serves as Ariadne's thread throughout the following.

2. Cooperative work

The term 'cooperation' has a wide variety of connotations in everyday usage, ranging from notions of joining alliances (as in the 'cooperative' movement) and being amicable and altruistic ('You should be more cooperative') to actually working together in producing a product or service irrespective of whether those working together are allies or friends.

In some areas of social research, in particular political science, institutional economics, and organizational theory, the term 'cooperation' has been used broadly to designate the formation of coalitions between actors with partially divergent interests and motives. For instance, in his influential investigation of institutional economics, John Commons uses the term in the strong sense of subjection of the centrifugal forces of conflicting individual interests to a putative common cause and collective action:

> "coöperation […] arises from the necessity of *creating a new harmony* of interests — or at least order, if harmony is impossible — out of the conflict of interests among the hoped-for coöperators. It is the negotiational psychology of persuasion, coercion, or duress. The greatest American piece of actual coöperation, latterly under ill repute [anno 1934], is the holding

> companies which suppress conflicts, if persuasion proves inadequate. A more universal coöperation, suppressing conflict in behalf of order, is proposed by Communism, Fascism, or Nazism. These have found their own ways of submerging conflicts of interest." (Commons, 1934, pp. 6 f.)

The conception of 'cooperation' as a governance structure for curbing opportunistic behavior among actors does not provide an adequate approach to CSCW. Of course, opportunistic behavior is part and parcel of working life, under the auspices of "common ownership" as well as on the "open market". In designing CSCW system this fact of life must certainly be taken into account (Kling, 1980; Grudin, 1989; Orlikowski, 1992). But if this conception is taken to provide the general conceptual framework for CSCW, essential aspects of the multi-faceted phenomenon of cooperative work is marginalized or simply lost: the work itself, the complex material interdependencies between actors, the role of artifacts in mediating interactions and the different affordances and constraints offered by different artifacts in that respect, the multifarious technical and social skills required, the continuous effort of maintaining mutual awareness and making one's own activities publicly visible, the mutual help.

In other words, the concept of 'cooperation' does not enable us to grasp the rich multiplicity of interdependency and reciprocity among actors in cooperative work arrangements. It only allows us to conceive of a world of partially conflicting and mutually repellent actors whose only interactions take the abstract form of allocations of resources.

On the other hand, however, the term 'cooperative work', chosen by Greif and Cashman to designate the object domain of the new R&D area of CSCW, also happens to be a term with a long history in the social sciences. It was used as early as the first half of the 19th century by economists such as Ure (1835) and Wakefield (1849) as the general and neutral designation of work involving multiple actors and was further developed by Marx (1867) who defined it as "multiple individuals working together in a conscious way [planmässig] in the same production process or in different but connected production processes." In this century, the term has been used extensively with the same general meaning by various authors, especially in the German tradition of the sociology of work (e.g., Popitz et al., 1957; Bahrdt, 1958; Dahrendorf, 1959; Kern and Schumann, 1970; Mickler et al., 1976).

This concept of 'cooperative work' is, surely, the appropriate starting point for developing a conceptual framework of cooperative work for CSCW systems design (Bannon and Schmidt, 1989).

At the core of this conception of cooperative work is the notion of *interdependence in work*. in the sense that *cooperative work occurs when multiple actors are required to do the work and therefore are mutually dependent in their work and must coordinate and integrate their individual activities to get the work done* (Schmidt, 1991). We will discuss the notion of interdependence at length below. First, however, we need to discuss *why* we need to distinguish cooperative work from work in general — in view of the fact that all work is essentially social.

According to Montesquieu, “Man is born in society and there he remains.”[4] In the same vein, Marx (1857) posited that

> “Individuals producing in society — hence socially determined individual production — is, of course, the point of departure. The individual and isolated hunter and fisherman, with whom Smith and Ricardo begin, belong among the unimaginative conceits of the eighteenth-century Robinsonades” (p. 21).

Marx’ critique of the Robinson Crusoe metaphor is rooted in a conception of work as an intrinsically social phenomenon:

> “Human kind is, in the most literal sense, a zoon politikon, not merely a social animal but an animal which can individuate itself only in the midst of society. Production by an isolated individual outside society — a rare exception which may well occur when a civilized person in whom the social forces are already dynamically present is cast by accident into the wilderness — is as much of an absurdity as is the development of language without individuals living *together* and talking to each other.” (Marx, 1857, p. 22)

In work, that is, the social setting is ubiquitous. Work is always immediately social in that the object and the subject, the end and the means, the motives and the needs, the implements and the competencies, are socially mediated. The social nature of work is not a static property, however; it develops historically. With the ever deeper and increasingly comprehensive social division of labor, the subject and object of work, etc. become increasingly social in character. Hunter-gatherers, for instance, work in an environment that is appropriated socially and yet to a large extent naturally given, whereas, in the case of operators in modern chemical plants, every aspect of work is socially mediated — to the extent that it is conducted in an ‘artificial reality’.

While work is always socially situated and socially organized, the very work process is not always cooperative in the sense that it requires and involves multiple actors who are thus interdependent in their work.

Now, in cooperative work settings, cooperative and individual activities are inextricably interwoven. Cooperative work is always conducted by individuals (albeit interdependently and hence concertedly). And still, individual activities are always penetrated and saturated by cooperative work as by a social ‘ether’ — so that, in any given case, it may be impossible to determine whether a given activity is part of a cooperative activity (Hughes et al., 1991; Heath and Luff, 1992).

So, why make the distinction? Because, if actors are interdependent in their work, then they objectively need to coordinate and integrate their individual activities to get the work done.

Work does not always involve multiple actors who are mutually dependent in their work and therefore required to coordinate and integrate their individual acti-

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4 Actually, Montesquieu does not quite put it this way: “Je n’ai jamais ouï parler du droit public qu’on n’ait commencé par rechercher soigneusement quelle est l’origine des sociétés, ce qui me paraît ridicule. Si les hommes n’en formaient point, s’ils se quittaient et se fuyaint les uns les autres, il faudrait en demender la raison et chercher pourquoi ils se tiennent séparés. Mails ils naissent tous liés les uns aux autres; uns fils est né auprès de son père, et il s’y tient: voila la societé et la cause de la société.” (Montesquieu, 1721, Lettre xciv, p. 153)— The wording of the quote is Ferguson’s apt rendition (Ferguson, 1767, p. 16).

vities. We are social animals, but we are not *all* of us *always* and in *every* respect mutually dependent in our work. Thus, in spite of its intrinsically social nature, work is not intrinsically cooperative in the sense that actors are mutually dependent in their work. As observed by Popitz and associates in their classic work:

> "It is not sufficient to remark that the individual work activities are embedded within a larger work context. One must be more concrete and with each individual work activity demonstrate *how* and *to what extent* cooperation with other work activities is a requirement. In doing so, the following issues seem to be important: Is a work activity determined by other work activities and does it, in turn, determine others? What kind of dependency? How does it show? Furthermore: Does a certain work activity require assistance or not? Is mutual assistance possible or even necessary? Or is each worker so preoccupied with his own work that a mutual support is not possible?"(Popitz et al., 1957, p. 41)

Consequently, if actors are not mutually dependent in their work and therefore not required to coordinate and integrate their individual activities, they may not need the support of CSCW systems. In that case, a 'shared' information system is merely a pooled resource in the sense that it is provided under the auspices of the 'common ownership' of a firm. The actors may — *or may not* — find it in their individual interests to actually 'share' this resource, for instance by providing information to others via the system (Orlikowski, 1992).

That is, as soon as we abandon the specific notion of cooperative work as constituted by interdependent activities for the notion of the social nature of all work, we are back with the issues of designing information systems in general.

Let us therefore explore the concept of cooperative work a little further.

2.1. The emergent nature of cooperative work

Generally speaking, cooperative work relations are formed because of the limited capabilities of single human individuals, that is, because the work could not be accomplished otherwise, or at least could not be accomplished as quickly, as efficiently, as well, etc., if it was to be done on an individual basis:

> "If we eliminate from consideration personal satisfaction […], their coöperation has no reason for being except as it can do what the individual cannot do. Coöperation justifies itself, then, as a means of overcoming the limitations restricting what individuals can do." (Barnard, 1938, p. 23)

More specifically, cooperative work arrangements emerge in response to different requirements and may thus serve different generic functions (Schmidt, 1990):

Augmentation of capacity: A cooperative work arrangement may simply augment the mechanical and information processing capacities of human individuals and thus enable a cooperating ensemble to accomplish a task that would have been infeasible for the actors individually. As an ensemble they may, for instance, be able to remove a stone that one individual could not move one iota. In the words of John Bellers: "As one man cannot, and 10 men must strain, to lift a tun of weight, yet one hundred men can do it only by the strength of a finger of each of them." (Bellers, 1696, p. 21). This is cooperative work in its most elemental form. By cooperating, they simply augment their capacity: “With simple cooperation it is only the mass of human power that has an effect. A monster with multiple eyes, multiple arms etc. replaces one with two eyes etc.” (Marx, 1861-63, p. 233□)

Differentiation and combination of specialties: A cooperative work arrangement may combine multiple *technique-based specialties*. In augmentative cooperation the allocation of different tasks to different actors is incidental and transitory; the participants may change the differential allocation at will. By contrast, technique-based specialization requires an “exclusive devotion” to a set of techniques (de Tracy, 1826, p. 79). That is, as opposed to the contingent and reversible differentiation of tasks that may accompany augmentative cooperation, the *technique-based specialization is based on an exclusive devotion to a repertoire of techniques*. In the words of the eulogist of technique-based specialization, Adam Smith: “the division of labour, by reducing every man’s business to some one simple operation, and by making this operation the sole employment of his life, necessarily increases very much the dexterity of the workman” (Smith, 1776, p. 7). The different techniques must be combined, however, and the higher the degree of technique-based specialization, the larger the network of cooperative relations required to combine the specialties (Babbage, 1832, §§ 263-268, pp. 211-216). That is, *technique-based specialization requires combinative cooperation*. This combinative cooperation is defined by Marx as “cooperation in the division of labor that no longer appears as an aggregation or a temporary distribution of the same functions, but as a decomposition of a totality of functions in its component parts and unification of these different components” (Marx, 1861-63, p. 253). Hence, the combination of multiple technique-based specialties assumes the character of a mechanical totality in which the human actors are assigned the role of a component. In the words of Ferguson’s classic denunciation of this kind of division of labor: “Manufactures […] prosper most, where the mind is least consulted, and where the workshop may, without any great effort of imagination, be considered as an engine, the parts of which are men.” (Ferguson, 1767, p. 183)

Mutual critical assessment: A cooperative work arrangement may facilitate the application of multiple problem-solving *strategies and heuristics* to a given problem and may thus ensure relatively balanced and objective decisions in complex environments. Under conditions of uncertainty, decision making will require the exercise of discretion. In discretionary decision making, however, different individual decision makers will typically have preferences for different heuristics (approaches, strategies, stop rules, etc.). Phrased negatively, they will exhibit different characteristic ‘biases’. By involving different individuals, a cooperative work arrangement in a complex environment becomes an arena for different decision making strategies and propensities where different decision makers subject the reliability and trustworthiness of the contributions of their colleagues to critical evaluation (Schmidt, 1990). As an ensemble they are thus able to arrive at more robust and balanced decisions. For example, take the case of an “experienced and skeptical oncologist,” cited by Strauss and associates:

> "I think you just learn to know who you can trust. Who overreads, who underreads. I have got X rays all over town, so I've the chance to do it. I know that when Schmidt at Palm Hospital says, 'There's a suspicion of a tumor in this chest,' it doesn't mean much because she, like I, sees tumors everywhere. She looks under her bed at night to make sure there's not some cancer there. When Jones at the same institution reads it and says, 'There's a suspicion of a tumor there,' I take it damn seriously because if he thinks it's there, by God it probably is. And you do this all over town. Who do you have confidence in and who none." (Strauss et al., 1985)

The point is, as observed by Cicourel (1990, p. 222), that "the source of a medical opinion remains a powerful determinant of its influence." That is, "physicians typically assess the adequacy of medical information on the basis of the perceived credibility of the source, whether the source is the patient or another physician." Thus "advice from physicians who are perceived as 'good doctors' is highly valued, whereas advice from sources perceived as less credible may be discounted." This process of mutual critical evaluation was described by Cyert and March (1963) who aptly dubbed it 'bias discount.' Because of this, the transmission of dubious assessments and erroneous decisions due to characteristic individual biases to other decision makers, does not necessarily entail a diffusion or accumulation of mistakes, misrepresentations, and misconceptions within the decision-making ensemble at large. In other words, the cooperating ensemble establishes a negotiated order.

Confrontation and combination of perspectives: A cooperative work arrangement may finally facilitate the application of multiple *perspectives* on a given problem so as to match the multifarious nature of the field of work. A perspective, in this context, is a particular — local and temporary — conceptualization of the field of work, that is, a conceptual reproduction of a limited set of salient structural and functional properties of the field of work, such as, for instance, generative mechanisms, causal laws, and taxonomies, and a concomitant body of representations (models, notations, etc.).

To grasp the diverse and contradictory aspects of a composite field of work, its multifarious nature must be matched by a concomitant multiplicity of perspectives on the part of the cooperating ensemble (Schmidt, 1990). The application of multiple perspectives will typically require the joint effort of multiple agents, each attending to one particular perspective and therefore engulfed in a particular and parochial small world.

To cope with this multiplicity, the cooperative ensemble must articulate (interrelate and compile) the partial and parochial perspectives by transforming and translating information from one level of conceptualization to another and from one object domain to another (Schmidt, 1990).

An issue, raised by Charles Savage in a 'round table discussion' on Computer Integrated Manufacturing (Savage, 1987) illustrates this issue quite well:

> "In the traditional manual manufacturing approach, human translation takes place at each step of the way. As information is passed from one function to the next, it is often changed and adapted. For example, Manufacturing Engineering takes engineering drawings and red-pencils them, knowing they can never be produced as drawn. The experience and collective wisdom of

each functional group, usually undocumented, is an invisible yet extremely valuable company resource."

This fact is ignored by the prevailing approach to CIM, however:

"Part of the problem is that each functional department has its own set of meanings for key terms. It is not uncommon to find companies with four different parts lists and nine bills of material. Key terms such as *part*, *project*, *subassembly*, *tolerance* are understood differently in different parts of the company."

The problem is not merely terminological. It is the problem of multiple incommensurate perspectives. The issue raised by Savage is rooted in the heterogeneity of the field of work and the contradictory functional requirements to be satisfied by the cooperative ensemble. In Savage's words: "Most business challenges require the insights and experience of a multitude of resources which need to work together in both temporary and permanent teams to get the job done".

In sum, a cooperative work arrangement arises simply because there is no omniscient and omnipotent agent.

Because of the underlying and constitutive interdependence, a cooperative effort involves a number of secondary activities of coordinating and integrating these cooperative relationships. In other words, the cooperating actors have to *articulate* (divide, allocate, coordinate, schedule, mesh, interrelate, etc.) their individual activities (Strauss, 1985; Gerson and Star, 1986; Strauss, 1988). Tasks have to be allocated to different members of the cooperative work arrangement: which actor is to do what, where, when?

By entering into cooperative work relations, the participants must engage in activities that are, in a sense, extraneous to the activities that contribute directly to fashioning the product or service and meeting requirements. That is, compared to individual work, cooperative work implies an overhead cost in terms of labor, resources, time, etc. This point is clearly illustrated by the following observation from the study of air traffic control by Hughes and associates:

"The limit to the existing [Air Traffic Control] system is the human controller and the capacity he/she can cope with safely [...]. In other words, it is the workload limit of controllers which determine the capacity of a sector. An apparent solution to capacity problems is to subdivide the airspace into a larger number of smaller sectors. However, this problem is exacerbated by the fact that as the number of sectors increases, so too do the coordination and handover elements of the workload, so that the potential gain is negated." (Hughes et al., 1988, pp. 33 f.).

The obvious justification for incurring this overhead cost and thus the reason for the emergence of cooperative work formations is, of course, that the actors in question could not accomplish the given task if they were to do it individually (Schmidt, 1990).

Conceived of in this way, cooperative work arrangements are transient formations, emerging contingently to handle specific requirements — in response to the requirements of the current situation and the technical and human resources at hand — merely to dissolve again when there is no need for multiple actors and their coordinated effort to handle situations.

That is, cooperative work arrangements arise from and dissolve into individual work. More than that, the boundary between individual and cooperative work is dynamic in the sense that people enter into cooperative work arrangements and leave them according to the requirements of the current situation and the technical and human resources at hand. Cooperative activities are punctuated by individual activities and vice versa. Over time, people shift between individual and cooperative activities and, while engaged in cooperative work activities, they may be simultaneously involved in parallel streams of activity conducted individually.

2.2. The evolutionary character of cooperative work

Since cooperative work arrangements require an overhead cost of coordination and articulation work, they should be conceived of as emergent formations.

For example, in a study of the impact of technology on cooperative work among the Orokaiva in New Guinea, Newton (1985) observes that technological innovations for hunting and fishing such as shotguns, iron, torches, rubber-propelled spears, and goggles have made individual hunting and fishing more successful compared to cooperative arrangements. As a result, large-scale cooperative hunting and fishing ventures are no longer more economical or more efficient and they are therefore vanishing. Likewise, the traditional cooperative work arrangements in horticulture for purposes such as land clearing and establishment of gardens have been reduced in scope or obliterated by the influence of the steel ax. A similar shift from cooperative to individual work can be observed wherever and whenever new technologies augment the capabilities of individual actors to accomplish the task individually: harvesters, bulldozers, pocket calculators, word processors, etc.

Cooperative work relations emerge in response to the requirements and constraints posed by the field of work and the wider work environment on one hand and the limitations of the technical and human resources available on the other. Accordingly, cooperative work arrangements adapt dynamically to the shifting conditions and demands under which the work is carried out and the characteristics and capabilities of the technical and human resources at hand. Different requirements and constraints and different technical and human resources engender different cooperative work arrangements.

As befits an emergent phenomenon, cooperative work develops historically. For example, agricultural work and craft work of pre-industrial society was only sporadically cooperative. Due to the low level of division of labor at the point of production, the bulk of human labor was exerted individually or within very loosely coupled arrangements. There were, of course, notable exceptions to this picture such as harvest and large building projects (e.g., pyramids, irrigation systems, roads, cathedrals), but these examples should not be mistaken for the overall picture.

Cooperative work as a systematic arrangement of the bulk of work at the point of production emerges in response to the radical division of labor in manufactories that inaugurated the Industrial Revolution. In fact, systematic cooperation in production can be seen as the 'base line' of the capitalist mode of production. However, cooperative work based on the division of labor in manufactories is essentially amputated: the interdependencies between the specialized operators in their work are mediated and coordinated by means of a hierarchical systems of social control (foremen, planners etc.) and by the constraints embodied in the layout and mode of operation of the technical system (conveyer belt etc.). In Marx' words:

> "To the workers themselves, no combination of activities occurs. Rather, the combination is a combination of narrow functions to which every worker or set of workers as a group is subordinated. His function is narrow, abstracted, partial. The totality emerging from this is based on this *utterly partial existence* and isolation in the particular function. It is thus a combination of which he constitutes a part, based on his work not being combined. *The workers are the building blocks of this combination*. The combination is not their relationship and it is not subordinated to them as an association." (Marx, 1861-63, p 253)

The societal precondition for the prevalence of this 'fetishistic' form of cooperative work is that manufacturing and administrative organizations are in control of their environment to the extent that they can curtail its complex and dynamic character. By severely limiting the range of products and services offered and by imposing strict schedules and procedures on their customers and clientele, organizations in branches of mass production and mass-transactions processing were able to contrive synthetic work settings where activities, for all practical purposes, could be assumed to be subsumed under preconceived plans.

Taking the fundamental trends in the political economy of contemporary industrial society into consideration, the 'fetishistic' form of cooperative work is probably merely a transient form in the history of work. Comprehensive changes of the societal environment permeate the realm of work with a whole new regime of demands and constraints. The business environment of modern manufacturing, for instance, is becoming rigorously demanding as enterprises are faced with shorter product life cycles, roaring product diversification, minimal inventories and buffer stocks, extremely short lead times, shrinking batch sizes, concurrent processing of multiple different products and orders, etc. (cf. Gunn, 1987). The turbulent character of modern business environments and the demands of an educated and critical populace, compel industrial enterprises, administrative agencies, health and service organizations, etc. to drastically improve their innovative capability, operational flexibility, and product quality. To meet these demands, work organizations must be able to adapt rapidly and diligently and still be able to fluently coordinate their distributed activities. And this requires horizontal and direct cooperation across functions and professional boundaries within the organization or within a network of organizations.

In short, the full resources of cooperative work must be unleashed: horizontal coordination, local control, mutual adjustment, critique and debate, self-organization. Enter CSCW.

In order to support and facilitate the articulation of distributed and dispersed work activities, modern work organizations need support in the form of advanced information systems. This is illustrated by the efforts in the area of Computer Integrated Manufacturing to integrate formerly separated functions such as design and process planning, marketing and production planning, etc., and by the efforts in the area of Office Information Systems to facilitate and enhance the exchange of information across geographical distance and organizational and professional boundaries. Common to the efforts in these very different areas are the issues explored by CSCW: How can computer systems assist cooperating ensembles in developing and exercising horizontal coordination, local control, mutual adjustment, critique and debate, and self-organization?

2.3. Interdependence in general and interdependence in work

Whatever the specific requirement (or combination of requirements) engendering the emergence of a particular cooperative work arrangement, actors engaged in cooperative work are *mutually dependent in their* work.

The notion of mutual dependence *in work* does not refer to the interdependence that arises from simply having to share the same resource. Actors using the same resource certainly have to coordinate their activities but to each of them the existence of the others is a mere nuisance and the less their own work is affected by others the better. Time-sharing facilities cater for just that by making the presence of other users imperceptible. Being mutually dependent *in work*, on the other hand, means that A relies positively on the quality and timeliness of B's work and vice versa. B may be 'down stream' in relation to A but in that case A nonetheless will depend on B for feedback on requirements, possibilities, quality problems, schedules, etc. In short, mutual dependence in work should primarily be conceived of as a positive, though by no means necessarily harmonious, interdependence.

This conception of interdependence in work as constitutive of cooperative work is somewhat related to Thompson's concept of "internal interdependence" (Thompson, 1967, pp. 54-55). There a some significant differences, however, that need to be discussed. In his classic study Thompson makes a distinction between three "types of interdependence":

Pooled interdependence:

> "The Tuscaloosa branch of an organization may not interact at all with the Oshkosh branch, and neither may have contact with the Kokomo branch. Yet they may be interdependent in the sense that unless each performs adequately, the total organization is jeopardized; failure of any one can threaten the whole and thus the other parts. We can describe this situation as one in which each part renders a discrete contribution to the whole and each is supported by the whole. We will call this *pooled interdependence*." (Thompson, 1967, p. 54)

Sequential interdependence:

> "Interdependence may also take a serial form, with the Keokuk plant producing parts which becomes inputs for the Tucumcari assembly operation. Here both make contributions to and

are sustained by the whole organization, and so there is a pooled aspect to their interdependence. But, in addition, direct interdependence can be pinpointed between them, and the order of that interdependence can be specified. Keokuk must act properly before Tucumcari can act; and unless Tucumcari acts, Keokuk cannot solve its output problems. We will refer to this as *sequential interdependence*, and note that it is not symmetrical.” (Thompson, 1967, p. 54)

Reciprocal interdependence:

“A third form of interdependence can be labeled reciprocal, referring to the situation in which the outputs of each become inputs for the others. This is illustrated bye the airline which contains both operations and maintenance units. The production of the maintenance unit is an input for operations, in the form of a serviceable aircraft; and the product (or by-product) of operations is an input for maintenance, in the form of an aircraft needing maintenance. Under conditions of reciprocal interdependence, each unit involved is penetrated buy the other. There is of course, a pooled aspect to this, and there is also a serial aspect since the aircraft in question is used by, then by the other, and again by the first. But the distinguishing aspect is the reciprocity of the interdependence, with each unit posing contingency for the other.” (Thompson, 1967, pp. 54-55)

Summing up, Thompson observes:

“In the order introduced, the three types of interdependence are increasingly difficult to coordinate because they contain increasing degrees of contingency. With pooled interdependence, action in each position can proceed without regard to action in the other positions so long as the overall organization remains viable. With sequential interdependence, however, each position in the set must be readjusted if any one of them acts improperly or fails to meet expectations. There is always an element of potential contingency with sequential interdependence. With reciprocal interdependence, contingency is not merely potential, for the actions of each position in the set must be adjusted to the actions of one or more others in the set.” (Thompson, 1967, p. 55)

In the context of understanding cooperative work, Thompson’s notion of interdependence is problematic. The reason being that the issue pursued by Thompson is that of ‘the theory of the business firm’, not that of actual cooperative work arrangements.

Thus, the concept of pooled interdependence refers to the interdependence of units owned by the same firm, conglomerate, corporation, holding company, municipality, state, or whatever. The units do not interact in doing their work — they contribute financially to ‘the whole’, the firm etc. Thus, the fate of any one unit is certainly dependent on the *financial* performance of the other units and, consequently, the *financial* performance of the collection of units as a whole and they are thus quite interdependent, but only financially.

The sequential interdependence, on the other hand, is obviously an interdependence constituted by the productive activities of the units: The output of A’s activities becomes the input for B’s activities. The same applies to pooled interdependence defined as “the situation in which the outputs of each become inputs for the others”.

The distinction between sequential and reciprocal interdependence is not quite clear, however. In so far as the terms ‘input’ and ‘output’ refer to the flow of materials, components, products, and services, there is a clear difference between sequential and reciprocal interdependence. For example, if the outcome of A’s activities provide the input (material, components etc.) for B's activities, B obviously depends on A in terms of quality, quantity, schedules etc. But the interdependence is not strictly one-directional. A also depends on B, albeit in other ways — not only to "solve its output problem" but also to provide feedback on quality problems and the like. A and B depend on each other to do their respective work but they depend on each other in different ways. In reciprocal interdependence, the outputs of each become inputs for the others. They are reciprocally interdependent in the sense that each of the units in its work depends of the performance of the others in terms of quality, quantity, schedules etc. as well as feedback.

It is worth noting that Thompson's example of reciprocal interdependence in an airline is quite misleading. While Maintenance certainly provides an output for Operations in the form of a serviceable aircraft and Operations thus, in its work, clearly depends on Maintenance, Operations does not *produce* "aircraft needing maintenance". In so far as the difference between sequential and reciprocal interdependence is defined in terms of the direction of input-output relations, the interdependence between Maintenance and Operations of an airline is just another example of sequential interdependence. In discussing the difference between sequential and reciprocal interdependence, however, Thompson introduces a new definition of reciprocal interdependence: "the distinguishing aspect is the reciprocity of the interdependence, with each unit posing contingency for the other." And, in fact, he eventually seems to define the different types of interdependence and interdependence as such by means of the concept of contingency. Whether that is a reasonable way of conceptualizing the interdependence of the parts of the organization in the context of the theory of the business firm and its structure is beyond the scope of this report, but it is far too general and inclusive to conceptualize actual cooperative relations of work. The various units of an organization (or a market for that matter) pose contingencies for each other in innumerable ways: not only by means of productive activities whose outcome others take as input for their productive activities, but also by demanding a product or service, by being owned by the same firm and thus partaking in the same financial and administrative arrangements and sharing the same corporate image in public, by being involved in the internal politics of the firm, by competing with others, and so forth. What we need to study, however, is the cooperative work relations that emerge between people that mutually depend on each other's productive activities in order to do their work.

In order to understand these interdependencies and how they determine cooperative practices, we need to introduce the concept of the 'field of work', that is, the part of the world that is being transformed or otherwise controlled by the cooperative work arrangement.

2.4. The common field of work

Having entered into a cooperative work arrangement, the actors cooperatively and interactively transform and control a conglomerate of *mutually interacting* objects and processes, the field of work. That is, their interdependence in their work is constituted by the interdependencies between the objects and processes constituting the field of work. Thus, all cooperative work is based upon interactions mediated through the changing state of *a common field of work*.

In order to illuminate this concept, consider the case of the hot rolling mill.

The hot rolling mill. The classic study by Popitz and others (1957) of cooperative work in the German steel industry provides an eloquent example of "structurally mediated cooperation" or cooperative work mediated by a technical system, in this case cooperative manual control of a rolling mill that shapes hot steel ingots into strips of different forms and dimensions.[5]

The basic transformation process of rolling metal is to reduce or change the cross-sectional area of a work piece — typically a hot ingot — by the compressive forces exerted by rotating rolls. The mill in question has a reversible double-roll of six different calibers (se Figure 1). The work piece — a 'strip' or 'slab' (Block) — is formed as it passes through the rolls and is shifted from caliber to caliber. Depending on the alloy of the particular strip and its temperature, the strip may require multiple passes at each caliber. The proper reduction per pass depends on the type of material and other factors. For example, Thomas steel requires fewer passes than the harder Siemens-Martin steel and hot strips require fewer passes than colder ones. After each pass the distance between the rolls is adjusted and after some passes the strip is tilted 90˚.

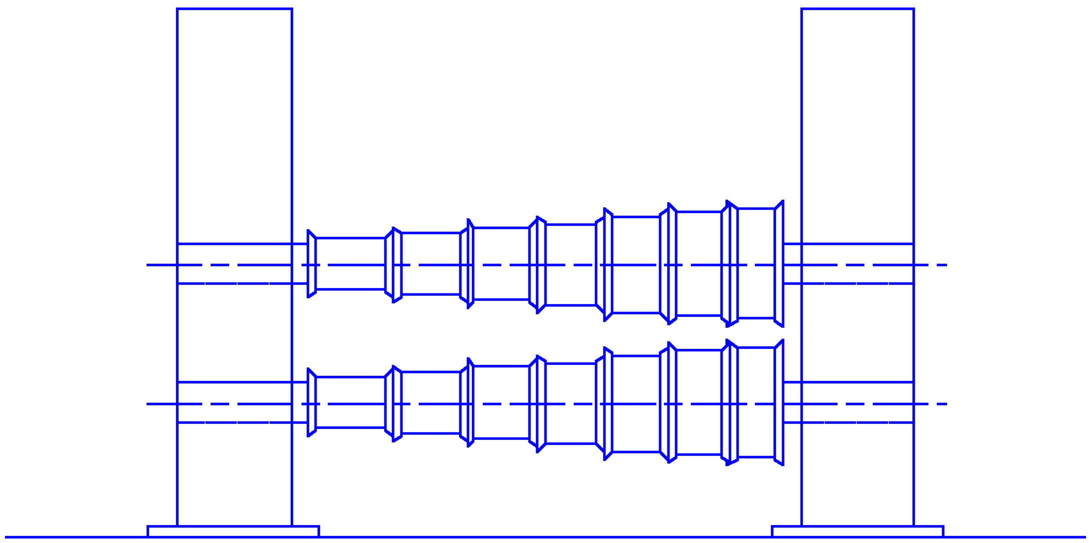

Figure 1. Cross section of the rolling mill stand showing the two six-caliber rolls. When being shaped, the strip is subjected to multiple passes at each caliber whereupon it is shifted to the next caliber, from left to right. The distance between the rolls is adjusted between each pass by the driver. (Popitz et al., 1957).

5 One should bear in mind that the study was conducted in the early 1950's. Modern rolling mills are quite different from the one described here. For example, the mill in the Popitz study is driven by steam! The study is used here, nonetheless, not only because it is a brilliant sociological study, but because it is an exceptionally clear and telling case of cooperative work mediated by the field of work.

The rolling mill is operated by four workers: a 'driver' (Steuermann), a 'tip cart operator' (Kippwagenführer), an 'engineer' (Walzenzugmaschinist), and a 'foreman' (Walzenmeister) or his deputy.

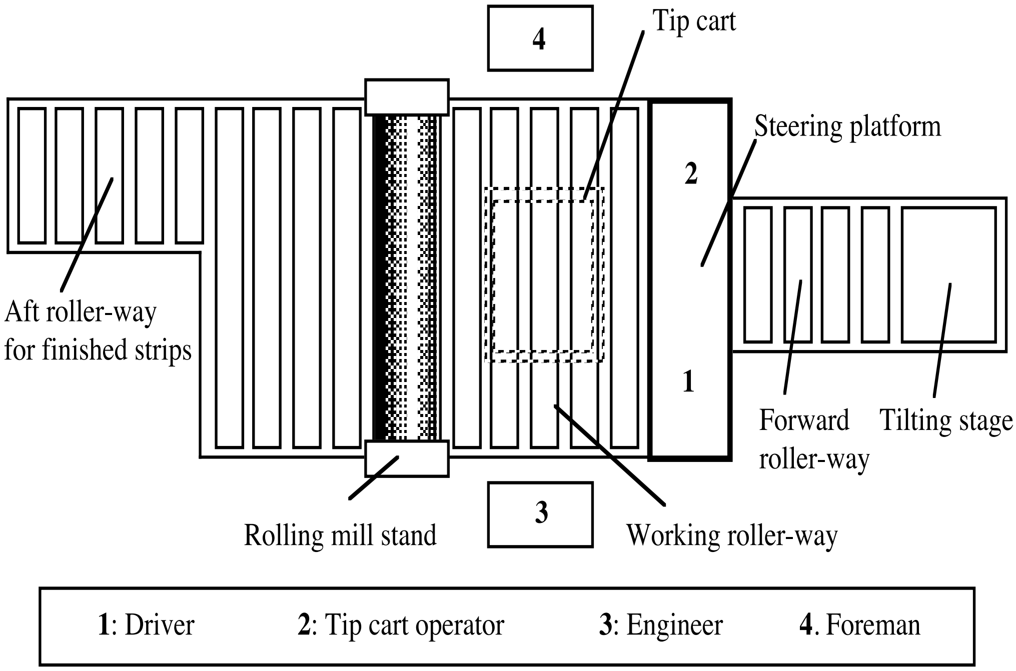

Figure 2. The rolling mill seen from above. (Popitz et al., 1957)

The driver and the tip cart operator are stationed on a bridge-like platform in a cabin from where they can see the process in front of and in the rolls but not the processes in the roller-way area behind the stand.

The driver controls the tilting stage and the forward roller-way that moves the incoming ingot forward towards the rolls. His main task, however, is to control the roller-way in front of the stand that makes the strip move to or from the rolls and to adjust the distance between the rolls for each pass at the same caliber.

The tip cart operator, on the other hand, tilts the strip between passes at the same caliber and, when a change of caliber is required, shifts the strip to another caliber. In addition, the tip cart operator controls the roller-way in the area behind the rolls, and moves the strip back to the rolls when a new pass is required. If the strip is not finished, he should not let it move too far to the rear; it has to be caught and moved back into the rolls at the same caliber.

If the strip has to be tilted for another pass at the same caliber, then this must be done while the the strip is in motion and while the driver adjusts the setting of the rolls. These operations must be carried out quickly in a fluently integrated way.

The engineer controls the speed and direction of rotation of the rolls. He is stationed next to the rolling mill, before the roll stand, but he is also unable to see the area behind the roll stand. Apart from occasional signs from the foreman, he has to rely on indirect indicators such as changing light intensity, glow from the hot strips, and vibrations. Thus, when the strip is moving forward, the engineer cannot see it coming out behind the rolls but the vibrations of the machine are conveyed by his control levers and he notices immediately when the friction between strip and rolls has ceased, the machine is running more smoothly, and the speed of rotation increases. He then stops and reverses the rotation of the rolls. The tip cart operator lets the strip move to the rolls again and as soon as it touches the rolls, the engineer starts the rolls again. The tip cart operator assists in making the rolls grip by letting the roller-way run backwards (pp. 58 f.).

The foreman supervises the work of the three others. He provides the specifications for the strips to the driver and the tip cart operator. The foreman's deputy monitors the rolling process and, when required, intervenes by giving instructions with a signal whistle.

As pointed out by Popitz and associates, the field of work in this case — the complex technical system and the transformation processes — is subjected to a "rigorous temporal order" (p. 60).

First, each operation requires a certain time whose minimum is determined and cannot be exceeded. Popitz and associates aptly refer to this as the "Eigenzeit" (intrinsic timing) of the technical system.

Second, for the strip to be rolled requires a certain temperature (for alloy steels, 930˚-1260˚C). An inadequate temperature will deteriorate the quality of the finished product which may have to be discarded. In the worst case, the rolls may break which amounts to an significant economic loss (p. 63). Since the temperature of the strip falls continuously, the whole operation is time critical. Any delay will reduce the temperature because of which the strip may need additional passes at each caliber which prolongs the process even further and so forth.

Third, the continuous succession of the various stages of the rolling process is a prerequisite for its success. For instance, the rolls will only receive the strip if it is in motion but the moving strip will only be received if the rolls starts moving in the very moment when the strip arrives. Thus, in the words of Popitz and his colleagues, "the work activities are subjected to a temporal order determined by the 'Eigenzeit' of the technical system, the prescribed succession of operations and the necessity of maintaining the continuity of the process" (p. 61).

In fact, the functional decomposition and allocation of work at the rolling mill is designed to ensure continuity. For example, when the strip has passed the rolls, the tip cart operator has to catch it with the aft roller-way and move it back to the rolls. The engineer then has to reverse the rolls in order to receive the strip. When it rolls out in front of the rolls, the driver has to catch it and move it to the tip cart so that it can be tilted or shifted to another caliber. "The work activities of one man depends on the activities of the others: Each does what he has to do so that another can do what he has to do. Consequently, the activities are mutually temporally determined" (p. 61).

The rigorous determinacy of the processes does not prevent variations and disturbances. A typical variation may arise when a particular ingot does not have the required temperature. The driver can see that from the color of the glowing ingot — it is too dark red. The driver may reject it and it is then picked up by the crane again and taken back to the furnace. However, if the driver deems it just hot enough and accepts it, he has to adjust the distance between the rolls to decrease the reduction per pass and allow for more passes. The tip cart operator observes the roll adjustment and apperceives immediately that the driver is planning for additional passes. From that he can infer that it will require more passes before the strip has to be tilted and that it will take longer until it can be shifted to the next caliber. The engineer also immediately apperceives this situation and operates the rolls more carefully than usual (pp. 62 f.).

The cooperating workers are — for all practical purposes — unable to coordinate their individual activities by talking to each other. The noise level prevents them from talking during work, and some of them cannot even see each other. It thus often happens that operators do not talk to each other during an eight-hour day. Furthermore, the operators are so intensely preoccupied with controlling a process that has its own intrinsic temporal order, that they do not have the time to talk or to watch the hand movements of each other (p. 185).

Thus, cooperative work mediated by the changing state of the field of work does not necessarily require participants to socialize beyond the immediate interaction.[6] It is, for instance, completely irrelevant to the tip cart operator whether the engineer is a good comrade or not. But his capability to drive a rolling mill is of utmost importance to him.

An operator only operates the system rationally and effectively if each operation is carried out with a view to the necessary cooperation with the others (p. 185). That is, he has to take into account the preceding, concurrent, and immediately ensuing operations.

Each operator is on his own in doing his work — but in such a way that his activity at any time fits closely into and continues the technical transformation process. Thus, every variation in the work of another of import for this technical process must immediately be countered by him by a variation in his own work. For example, if the driver notices that a relatively cold strip needs more passes he will adjust the setting of the rolls differently than normal. That signifies that the tip cart operator has to tip that strip two or four passes later. Similarly, if the strip bends — that can happen at the two last calibers — then the tip cart operator, the driver and the engineer have to modify their operations simultaneously.

The crew nevertheless manages to act in a concerted may without verbal communication and without watching the operations of each other. Each of them know what the others are doing by apperceiving the behavior of the mill: the mo-

6 It goes without saying that technically mediated cooperative work does not prevent a supplementary socialization. Close personal contacts may occur, for example fostered by guild traditions (Popitz et al., 1957, p. 185).

vement of the roller-way and the tip cart as well as the setting and direction of rotation of the rolls. In a normal rolling process this mediation is even reduced to one object: the glowing strip. Its motions indicates what the others are doing at any point in time. "The activities of each worker are thus apperceived on the basis of the behavior of the object that these activities assist in moving and transforming" (p. 187). The activities of any of them are being observed continually and intensely by the others — *by way of* the behavior of the strip and the mill.

The cooperative operation of the hot rolling mill is a telling example of cooperative work mediated by state changes in the common field of work:

(1) The field of work is strictly causally coupled; all sub-processes are subjected to a rigorous temporal order and have to be carried out in a continuous way.

(2) The operators are engaged in 'manual process control' (like a driver of a car); they are directly in control of processes and thus have to perform control actions continuously. Because they are in the 'first order' control loop, their distributed activities are subjected to the same rigorous temporal order as the processes themselves and have to be articulated in the same continuous way. The distributed activities of the operators are thus tightly interdependent.

(3) None of the operators can oversee the process as a whole from their respective stations and they cannot leave their respective stations during work either. To a large extent, they have to rely on indirect evidence (vibrations, light intensity, glow) in order to know the state of affairs.

(4) Furthermore, the operators are — for all practical purposes — unable to coordinate their individual activities by talking to or watching each other. The crew nevertheless manages to act in a concerted may without verbal communication. They succeed in doing so because what they have to coordinate between them is — first and foremost — the exact timing of their individual operations.

(5) The awareness of the intentions and actions of the other members of the crew — that is, the dynamic and mutual awareness that is a prerequisite for the articulation of their cooperative effort — is developed and maintained on the basis of intense observation of the behavior of the strip, the rolls, the roller-way, the tip cart, etc.

(6) Taken as a 'means of communication', the hot rolling mill is of quite restricted 'bandwith'; the turn-around time of the interaction is rigorously determined by the frequency of state changes in the field of work, and any message than one actor might want to convey to another is completely entangled in the state of the field of work. In fact, because of the rigorous temporal order their work is subjected to, a state change undertaken for any other reason than to control the rolling of the strip would endanger the operation and might jeopardize the mill. Thus, the behavior of the strip and the mill does not carry any message. The strip is just a strip, and whatever is done to it is done with the single purpose of transforming it the proper way. Instead, the operators simply take their cues from the state of the field of work and infer the actions and intentions of their colleagues from that.

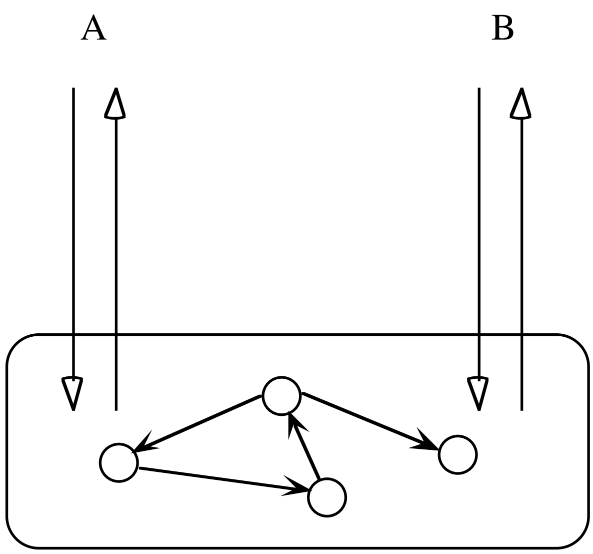

Figure 3. Cooperative work as mediated through the changing state of a common field of work.

Because of the complete absence of any interactions between operators that is not directly aimed at changing the state of the rolling mill and the ingot, the case of the hot rolling illustrates in a very clear way cooperative work in its elemental and fundamental form: *multiple actors interaction through changing the state of a common field of work* (Figure 3).

However, the case of the hot rolling mill may give the impression that the field of work is a thing. The field of work is not a thing — it is a conceptual construct that shall help us in analyzing and conceptualizing the formation and articulation of cooperative work arrangements:

First, the field of work and the cooperative work arrangement mutually constitute and delimit each other. The field of work is always the field of work for a particular cooperative work arrangement and the cooperative work arrangement is itself bounded and constituted by the interdependence of its activities as determined by the field of work. However, the field of work is not an arbitrary construct (in the vein of the infamous position of the 'softer' variant of 'systems thinking' that 'A system is what we take to be a system'). A field of work is constituted by interacting objects and coupled processes, just as a cooperative work arrangement is constituted by interdependent activities.

Second, the field of work itself is manifold (cf. Figure 4). It comprises, of course, the objects and processes of work but also the sensors and effectors as well as the more complex tools and control mechanisms that may have been inserted between the actors and the objects and processes. In addition, the field of work comprises the various representations of the state of the objects and processes and of the control systems (gauges, fixed line displays, radar screens, customer account data). Finally, the field of work may comprise — in an indeterminate way — the repertoire of potential material resources and technical artifacts (inventories of parts and other repositories, buildings, infrastructures) by means of which the production process may be performed.

Note that the field of work for some ensembles may comprise collections of data. The collection of archives of an administrative agency, for example, may be conceived of as a crucial part of the common field of work for the staff of the registry. Likewise, on a vastly greater scale, the global collection of data on causes of deaths can be conceived of as the common field of work of doctors, authorities, and other parties who are involved in producing international vital statistics and who for that purpose use the International Classification of Diseases (Bowker and Star, 1991).

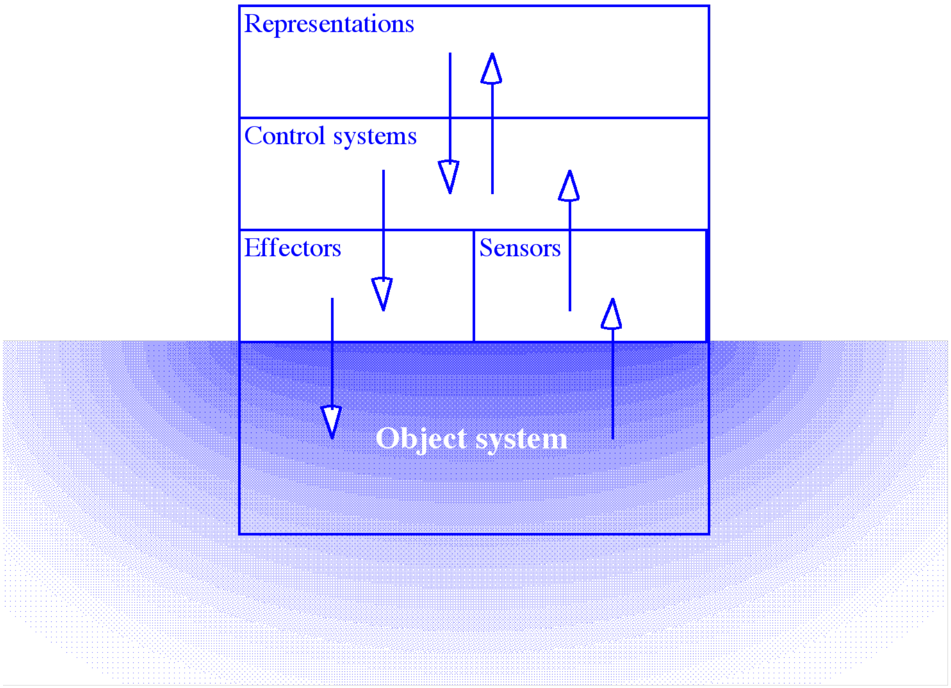

Figure 4. 'Component parts' of the field of work.

Third, the production process will be carried out in a wider environment which is not directly subsumed under of the field of work but nonetheless pose specific constraining characteristics and operational demands: the commercial, economic, environmental, legal demands and constraints that characterize the conditions under which the demands and constraints directly pertaining to the control of the field of work must be met. We will refer to this 'second order' environment, as *the work environment*.

Fourth, the actor-object relationship is a recursive phenomenon in the sense that some actor-object relationships are objects for other work processes (e.g., training, ergonomic intervention) and in the sense that some cooperative work arrangements are objects of work for other cooperative work arrangements (e.g., administration, ethnographic studies, and systems engineering).

And fifth, the boundary and character of the field of work may change dynamically. For example, when a ship meets another ship during its voyage, the field of work of the crew — basically, the ship and the water — "suddenly expands to include another ship" (Perrow, 1984, p. 178). Similarly, crews face fields of work that are basically different from the one they are faced with on the open ocean

> "when ships a city block long go into port with only two feet under their keel, with highly unpredictable suction effects and a virtual complete loss of maneuverability. [This] increases the time-dependent nature of the system and reduces the slack available (tighter coupling), and through increased proximity, brings into play poorly understood processes (the suction and bank effects), which rely upon indirect and inferential information sources (thus, more complex interactions are fostered)." (Perrow, 1984, p. 182).

2.5. The complexity of the field of work

The concept of a field of work has been introduced and used — under different labels — by a number of researchers as a conceptual construct for analyzing the salient characteristics of different work domains.

Charles Perrow (1984), for example, uses the term 'system' rather consistently, in his seminal comparative study of high-risk and high-tech work settings, in much the same sense as the term 'field of work' as defined above. The only significant difference is that Perrow — whose focus is on the etiology of system accidents, not on the formation and articulation of cooperative work arrangements — includes aspects of the work organization of the actors in the definition of 'the system'.

In order to be able to compare (the systemic risk-potentials of) different 'systems', Perrow suggests a two-dimensional framework: On one hand "complex and linear interactions" and on the other hand "tight and loose coupling", cf. the tables in Figure 5 and Figure 6:

Complex versus Linear Systems

Complex Systems	Linear Systems
Tight spacing of equipment	Equipment spread out
Proximate production steps	Segregated production steps
Many common-mode connections of components not in production sequence	Common-mode connections limited to power supply and environment
Limited isolation of failed components	Easy isolation of failed components
Personnel specialization limits awareness of interdependencies	Less personnel specialization
Limited substitution of supplies and materials	Extensive substitution of supplies and materials
Unfamiliar or unintended feedback loops	Few unfamiliar or unintended feedback loops
Many control parameters with potential interactions	Control parameters few, direct, and segregated
Indirect or inferential information sources	Direct, on-line information sources
Limited understanding of some processes (associated with transformation processes)	Extensive understanding of all processes (typically fabrication or assembly processes)

Figure 5. Aspects of complex versus linear systems (Perrow, 1984, p. 88).

Tight and Loose Coupling

Tight Coupling	Loose Coupling
Delays in processing not possible	Processing delays possible
Invariant sequences	Order of sequences can be changed
Only one method to achieve goal	Alternative methods available
Little slack possible in supplies, equipment, personnel	Slack in resources possible
Buffers and redundancies are designed-in, deliberate	Buffers and redundancies fortuitously available
Substitutions of supplies, equipment, personnel limited and designed-in	Substitutions fortuitously available

Figure 6. Aspects of tight and loose coupling (Perrow, 1984, p. 96).

Similarly, in the Cognitive Engineering approach to the design of decision support systems, Woods (1988) distinguishes different complexity factors for problem solving with respect to three basic elements (the Agent, the Representation, and the World). In his analysis the dimensions pertaining to the complexity posed by “the World”, Woods divides the two dimensions suggested by Perrow into four, namely Dynamism, Many Highly Interacting Parts, Uncertainty, and Risk:

Many Highly Interacting Parts:

> “When a world is made up of a large number of highly interconnected parts, one failure can have multiple consequences (produce multiple disturbances); a disturbance could be due to multiple potential causes and can have multiple potential fixes; there can be multiple relevant goals which can compete with each other; there can be multiple on-going tasks having different time spans. In addition, the parts of the world can be complex objects in their own right.” (Woods, 1988, p. 130)

Dynamism:

> “When a world is dynamic, problem-solving incidents unfold in time and are event-driven, that is, events can happen at indeterminate times. This element means that there can be time pressure, tasks can overlap, sustained performance is required, the nature of the problem to be solved can change, and monitoring requirements can be continuous or semi-continuous and change over time.”(Woods, 1988, p. 130)

Uncertainty:

> “When there is high uncertainty, available data can be ambiguous, incomplete, erroneous, low signal to noise ration, or imprecise with respect to the state of the world; the inferential value of data can vary with context; future states and events are not completely predictable. Uncertainty can be due to external occurrences, noise, changes in noise parameters over time, nonlinearities, time delays or the influence of previous events and inaccurate measurements can arise through sensor failures, miscalibrations or misentries.” (Woods, 1988, p. 130)

The emphasis on Risk as a separate dimension reflects the class of domains primarily addressed by Cognitive Engineering research. For our purposes, avoidance of Risk can be seen as one among many demands and constraints posed by the work environment in general (along with, say, flexibility, resource economy). In the context of cooperative work, the effect of Risk is to make the field of work tighter coupled (because actions may be irreversible under constraints of Risk).

The field of work of a particular cooperative work arrangement and, hence, the interdependencies between actors can thus be characterized in terms of specific configurations of complexty.

Structural complexity: The members of a cooperative work arrangement may interact through and in relation to a field of work characterized by different degrees of interactional complexity, in terms of number of objects and interdependencies. Moreover, when the field of work encompasses subsystems that are complex systems in their own right, cooperative work is likely involve multiple representations and conceptualizations of the domain and the cooperative effort thus involves transformations between different representations and conceptualizations (Mintzberg, 1979, p. 268; Rasmussen, 1988, pp. 176 f.; Star, 1989).

Temporal complexity: The members of a cooperative work arrangement may interact through and in relation to a field of work characterized by more or less dynamic behavior; by being more or less tightly coupled and hence time-critical or by having multiple partially concurrent, partially interdependent processes.

Apperceptive complexity: The members of a cooperative work arrangement may face a vast variety of problems in apperceiving (perceiving, making sense of, interpreting) the state of affairs in the field of work due to, for example, noise, unreliable sensors, indirect or inferential evidence, or from ambiguous or misleading information, and so forth.

2.5. The field of work and articulation work

As illustrated by the case of the hot rolling mill, changing the state of the field of work may be a treacherous channel of articulation work because interacting by inducing state changes in the field of work is a rudimental and unreliable mode of communication. Since many — if not most — cooperative work arrangements in modern industrial societies are faced with far more complex fields of work in terms of number of interacting processes and states, irreversibility, concurrency, uncertainty, and so forth, and since such arrangements therefore are faced with more complex interdependencies between individual activities, they cannot rely on accomplishing their cooperative effort merely by changing the state of the field of work; members of such arrangements must articulate their distributed activities by other means

Thus, as also pointed out above, in order to be able to conceptualize and specify the support requirements of cooperative work we need to make a fundamental analytical distinction between (a) cooperative work activities in relation to the state of the field of work and mediated by changes to the state of the field of work and (b) activities that arise from the fact that the work requires and involves multiple agents whose individual activities need to be coordinated, scheduled, meshed, integrated etc. — in short: *articulated*.

In order to clarify this distinction, compare the case of the hot rolling mill with the case of supervisory process control of a nuclear power plant:

The PWR control room. In the control of highly complex and automated processes, the control functions require more sophisticated articulation work than interaction via the field of work allows.

A recent study by Kasbi and Montmollin (1991) explores the impact on cooperative work practice of the planned radical computerization of control room design for the French 1500 MW power plants of the N4 PWR series. In order to study the impact of this putative “technological leap”, it was decided to connect a prototype of the advanced computer-based control room to a 1300 MW PWR process simulator called S3C. Operators running the S3C were observed and their performance was compared with field study findings from conventional control rooms.

In the power plants in question, two operators manage the control function. In some control situations (start-up or shut-down of plant units, incidents, etc.), there are prescribed, detailed procedures which organize the allocation of tasks between the two operators. The procedures are based on a subdivision of the process into a Primary side (nuclear reactor) and a Secondary side (water and steam). However, in most control situations, the operators are left free to decide how to allocate tasks between themselves. The organization of work — in particular, the allocation of responsibility for the Primary and Secondary systems between the operators — is far more flexible.

Since "two operators are really needed to control the process" (p. 281) and since the plant is a highly integrated technical complex and their activities therefore are complementary and interdependent, they must act in a highly coordinated fashion, and to do so each them needs access to reliable information on the state of the plant as a whole.

In traditional control rooms in nuclear power plants, information on the state of the plant is displayed on a panel that is several meters long; it is located in a room in which the operators both work. By contrast, in the S3C control room design each operator has a computer workstation. However, while these workstations provide access to all relevant control data, S3C have some interesting disruptive effects on the articulation work required for the two of them to control the plant jointly. At the beginning of the session, the operators normally agree on the allocation of the Primary and Secondary systems. However, in their work they often have to handle tasks concerning the side of the system initially assigned to the other operator. In a conventional control room this poses no problem. Each operator is continuously informed of the part of the process monitored by the other operator from the position of the other in relation to the instrument panel. From the changing positions of his colleague in the room, each of them can effortlessly infer what the other is up to. Furthermore, he only has to take a few steps to get a clearer idea of what is happening and in doing so he does not need to disturb the activities being carried out (p. 281).

> "Interactions between operators (oral exchanges, glances, movements to and fro), on the one hand, and the information sources available in the control room (alarms, pictures, mimic panel) are the means the operators working in pairs use to monitor the overall process and/or the other's activity." (p. 282)

That is, the specific characteristics of the conventional interface to the control system of the plant provide cues for operators to develop and maintain the required reciprocal awareness without forcing them to resort to verbal communication.[7]

In S3C, however, the formation of this reciprocal awareness is not supported by the design of the control room. Thus, in the case of the S3C articulation work requires precise verbalization and conscious and perhaps disruptive workstation management activities (p. 281).

As in the case of the rolling mill, the field of work of the operators — the power plant — is strictly causally coupled. However, the control of the transfor-

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7 A similar observation is given by Perrow: "I am told that one of the advantages of old-style steam valves, where the steam of the valve will rise when opened, is that a quick glance by an operator or supervisor over a huge room will show which valves are open, and which are shut — they just stick up when open. In an employee heads for the wrong valve after misunderstanding an order, that will be quite visible too. In complex systems, where not even a tip of an iceberg is visible, the communication must be exact, the dial correct, the switch position obvious, the reading direct and 'on-line'" (Perrow, 1984, p. 84).

mation of energy is mediated by a complex control system. Thus, whereas the manual process control of rolling mill imposes a rigorous temporal order on the activities of the operators, the operators of the power plant are engaged in 'supervisory process control' in the sense that they do not need to exercise control actions continuously (Sheridan and Ferrell, 1974; Rouse, 1980, p. 57). Because they are engaged in supervisory process control and their activities are not subjected to any rigorous temporal order, they can reallocate tasks between themselves. Also because they are engaged in supervisory process control, operators have no direct evidence of the state of the plant in the sense that they have no direct perceptual evidence of the energy transformation process. They rely on representations in the form of sensors and effectors to monitor and regulate the transformation process. What each of the operators is doing at any given time is therefore essentially invisible to the other. This impedes the formation of the reciprocal awareness required for articulation work.

Because the design of the conventional control room forces operators to move around in space in order to monitor and regulate the plant, it also supports the formation of reciprocal awareness. Again, like the operators of the hot rolling mill, they do not move to a particular panel in order to indicate to the other what they intend to do; their movements in the room are motivated by the requirements of the control function at any given time. However, unlike the operators of the hot rolling mill, they are able to develop and maintain a reciprocal awareness by observing each other.

Because the control of the energy transformation process is mediated by the automatic control system of the plant, the operators are able to articulate their activities in a flexible way: In addition to being able to develop and maintain reciprocal awareness by observing each other's movements, they are able to communicate verbally and visually. They are thus able to negotiate in ambiguous situations.

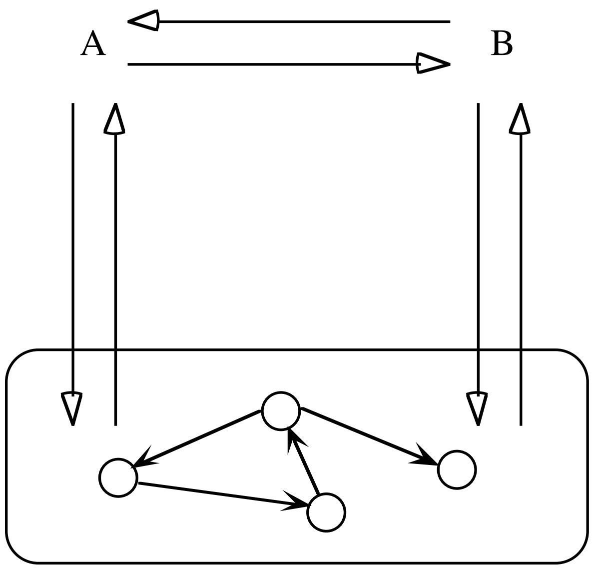

Figure 7. Articulation of distributed and yet interdependent activities.

2.6. The articulation of cooperative work

The concept of articulation work was developed by Strauss, Gerson, Star and others (Strauss, 1985; Strauss et al., 1985; Gerson and Star, 1986; Strauss, 1988) in order to handle the fact that cooperating actors, being mutually dependent in their work, have to *articulate* (divide, allocate, coordinate, schedule, mesh, interrelate, etc.) their individual activities: Who is doing what, where, when, how, by means of which, under which constraints?

In the words of Strauss (1985, p. 8), articulation work is "a kind of supra-type of work in any division of labor, done by the various actors":

> "Articulation work amounts to the following: First, the meshing of the often numerous tasks, clusters of tasks, and segments of the total arc. Second, the meshing of efforts of various unit-workers (individuals, departments, etc.). Third, the meshing of actors with their various types of work and implicated tasks."

Compared to such terms as 'coordination' or 'conversation for action', the concept of articulation work provides a number of advantages in a CSCW context: First, the concept of articulation work is more flexible than the connotations usually implied by the term 'coordination'. Articulation work connotes far more than mere scheduling and allocation of resources. In connotes, for instance, monitoring, handing over, resolving inconsistencies, reconciling incommensurate assumptions, opinions, and beliefs, and so forth. Second, the concept of articulation work specifically refers to the articulation of distributed and yet interdependent activities of multiple actors engaged in cooperative work. That is, is does not necessarily encompass the coordination of "multiple, interdependent activities" performed by only one actor.[8] Third, articulation work is conceived of with respect to the specific context, that is, in terms of the state of affairs in the field of work. And fourth, articulation work is conceived of as on-going articulation of cooperative work in face of unforeseen contingencies.

Thus, for example, the major problem with the 'conversation for action' metaphor (Winograd, 1986) is what is leaves out. The 'speech act' conception of articulation work ignores the articulation of meanings (concepts, categories, assumptions, beliefs). Moreover, in the 'conversation for action' approach articulation work is conceived of as an abstract, domain-independent generic activity — that is, the fact that work is articulated with reference to and in terms of the state of the field of work is not accounted for. In other words, the 'conversation for action' metaphor provides a strangely disembodied account of articulation work that it is hard to recognize in real-world settings, except, perhaps, in management committees and the like.

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8 Malone and Crowston define "coordination" as "the act of managing interdependencies between activities performed to achieve a goal" and add: "we have become convinced that the essential elements of coordination listed above arise whenever multiple, interdependent activities are performed to achieve goals — even if only one actor performs all of them" (Malone and Crowston, 1990, p. 361 f.). — A major problem with that approach is that it does not seem to provide a criterion for determining the level at which coordination is considered; in principle, all processes of the field of work at all semantic levels may be interdependent and may thus have to be coordinated.

2.7. The complexities of articulation work

Everything being equal, the more distributed the activities of the cooperative work arrangement, the more complex the articulation of the activities of that arrangement.

Even in the most routinized cooperative work arrangements, each individual encounters contingencies that may not have been anticipated by his or her colleagues and that, possibly, will remain unknown to them. Each participant in the cooperative effort is faced with a, *to some extent*, unique local situation that is, in principle, partially opaque to the others and each participant has to deal with this local situation individually. For example: misplaced documents, shortage of materials, delays, faulty parts, erroneous data, variations in component properties, design ambiguities and inconsistencies, design changes, changes in orders, cancellation of orders, rush orders, defective tools, software incompatibility and bugs, machinery breakdown, changes in personnel, illness, etc. That is, due to the fundamentally 'situated' nature of human action, cooperative work arrangements take on an inexorably distributed character.

Furthermore, the fact that the cooperative arrangement involves — and has emerged to facilitate — a combination of different specialties, incongruent heuristics, and incommensurate perspectives introduces a systematic element of distributed decision making in cooperative work.

And finally, work is an individual phenomenon in so far as labor power happens to be tied to individuals and cannot be separated from the individuals. That is, a cooperative work process is performed by individuals with individual interests and motives. Because of that, cooperative ensembles are coalitions of partially incongruent and even conflicting interests rather than perfectly collaborative systems. Thus, in the words of Ciborra (1985), the use of information for "misrepresentation purposes" is a daily occurrence in organizational settings. The Russian proverb saying that 'Man was given the ability of speech so that he could conceal his thoughts' applies perfectly to the use of information in organizations.

In sum, then, cooperative work is, in principle, distributed in the sense that actors are semi-autonomous in their work in terms of local contingencies, criteria, methods, specialties, perspectives, heuristics, interests, motives, and so forth.

Due to the very interdependence in work that gave rise to the cooperative work arrangement in the first place, the distributed nature of the arrangement must be kept in check, managed. Articulation work can thus be conceived of as a category of activities required to manage the distributed nature of cooperative work. Thus, in order to account for the distributed nature of cooperative work, Gerson and Star develops the concept of articulation work further by emphasizing its contingent and dynamic nature:

> "Reconciling incommensurate assumptions and procedures in the absence of enforceable standards is the essence of articulation. Articulation consists of all the tasks involved in assembling, scheduling, monitoring, and coordinating all of the steps necessary to complete a production task. This means carrying through a course of action despite local contingencies, unantici-

> pated glitches, incommensurate opinions and beliefs, or inadequate knowledge of local circumstances.
>
> Every real world system is an open system: It is impossible, both in practice and in theory, to anticipate and provide for every contingency which might arise in carrying out a series of tasks. No formal description of a system (or plan for its work) can thus be complete. Moreover, there is no way of guaranteeing that some contingency arising in the world will not be inconsistent with a formal description or plan for the system. [...] Every real world system thus requires articulation to deal with the unanticipated contingencies that arise. Articulation resolves these inconsistencies by packaging a compromise that 'gets the job done,' that is closes the system locally and temporarily so that work can go on." (Gerson and Star, 1986, p. 266)

Now, although it is crucial for CSCW systems design to maintain that cooperative work is distributed *in principle*, this general statement is insufficient for analyzing cooperative work for CSCW systems design. We need to understand the specific sources engendering the specific aspects of distributed decision making under specific conditions — only then is it possible to improve the ability of a cooperative ensemble to manage and curb the distributed nature of its cooperative effort.

In fact, the distributed character of cooperative work varies depending on a number of factors, e.g., the specific structural and temporal complexities of their interdependence as determined by the field of work (complex interactions, massive concurrency, intermittent interactions), the distribution of activities in time and space and the concomitant constraints on communications, the apperceptive complexity posed by the field of work and hence the discretionary nature of contributions of participants, the number of participants in the cooperative ensemble, the degree and scope of specialization required by the manifold nature of the field of work and hence the structural complexity of the cooperative work arrangement itself, the apperceptive complexity of assessing the state of affairs within the cooperative ensemble, and so on.

However, the different complexities encountered by the members of a cooperative work arrangement in articulating their distributed activities, do not follow in any direct and linear fashion from the complexity of the field of work or the complexity of the work.

First, the complexity of articulation work can be reduced by curtailing the need for cooperative work in the first place, e.g., by eliminating the number of interacting objects and processes in the field of work, or by introducing more powerful representations and control mechanisms between the objects and processes and the actors (Rasmussen and Lind, 1981).

Second, the complexity of articulation work can be reduced by curtailing the complexity of interdependencies between actors, e.g. by standardizing the activity of each actor viz-a-viz the common field of work so that the outcome of his or her actions becomes more reliable to others and thus less prone to provoke ad-hoc articulation, for instance by means of prescribed methods, standard routines, checklists, templates, etc.

In addition, the complexity of interdependencies between actors can be curtailed by changing the allocation of activities between actors so that the allocation of activities within the ensemble matches the interdependence between objects and processes. On the other hand, what may be gained by reducing, for example, the complexity of individual work by deepening the division of labor within the ensemble may be more than offset by an resultant increase of the burden of coordination.

3. Modes of articulation work

A cooperative work arrangement is constituted by the fact that multiple actors are interdependent in their work. In other words, they are working 'in' the same 'field of work', that is, they are transforming and controlling a conglomerate of *mutually interacting* objects and processes. Thus, all cooperative work involves and, indeed, is based upon interaction through changing the state of a common field of work. What one actor — A — is doing is of import to B and C in doing their work.

The other actors — C and B — may to some extent be able to infer what A is doing from the changing state of the field of work. However, while cooperating via the changing the state of the field of work is basic to all cooperative work, it is rarely adequate. In fact, articulation of cooperative work involves and, indeed, requires a vast variety of *modes of interaction* that are combined and meshed dynamically and seamlessly in accordance with the specific requirements of the unfolding work situation and the means of communication available.

In the following sections we will present some cases in which we can see the rich variety of articulation work at work.

3.1. The London Underground control room

The studies by Heath and Luff of cooperative work in Line Control Rooms on London Underground (Heath and Luff, 1991; Heath and Luff, 1992) provide detailed insight into the workings of the formation of reciprocal awareness among the operators of the line.

The operators in the control room coordinate train traffic and movement of passengers on a particular line, in this case the Bakerloo Line. The control room can house several staff, but concern here is with two main actors: the Line Controller who coordinates the day-to-day running of the railway and the Divisional Information Assistant (DIA) who, among other things, provides information to passengers and to Station Managers.

Both operators are able to monitor the state of the Bakerloo line traffic on a real-time display, a 'fixed line diagram', which runs the length of the room. In addition, a paper timetable specifies train numbers, times, and routes; crew allocations, shifts, and travel; vehicle storage and maintenance; etc. The Controller can contact train drivers via a radio system. The DIA, on the other hand, can monitor platforms via a closed circuit television (CCTV) and provide information to passengers via a Public Address system. In addition the DIA can establish contact with Station Managers by touch-screen phone.

Coordination of train traffic and passenger movement is a domain specific characteristic of rapid urban transport:

> "unlike other forms of transport, rapid urban transport systems do not provide a timetable to the public. Instead, passengers organise their travel arrangements on the assumption that trains will pass through particular stations every few minutes. When such expectations are broken, or travellers are unable to change at certain stations, or have to leave a train because the line is blocked, then the DIA needs to provide information and advice. The nature of such announcements varies with the circumstances of, and reasons for, their production." (Heath and Luff, 1992, p. 74)

Because the two controllers have to coordinate the movements of trains and passengers speedily and with minimal discomfort to the public, the activities of the Controller and the DIA require extremely close coordination. Accordingly, the operators have developed "a subtle and complex body of practices for monitoring each other's conduct and coordinating a varied collection of tasks and activities" (Heath and Luff, 1992, p. 73). One element of this informal, implicit and yet systematic articulation of responsibilities and tasks is "an emergent and flexible division of labour which allows the personnel to lend support to the accomplishment of each others' tasks and activities and thereby manage difficulties and crises" (pp. 73 f.).

As in the case of the operators of the nuclear power plant, the operators of the Bakerloo Line need to be able to articulate their activities tacitly:

> "It is relatively unusual for the Controller or the DIA to tell each other what tasks they are undertaking or explicitly to provide information concerning: the changes they have made to the service, the instructions they have provided to other personnel, or the announcements they have made to passengers. Indeed, given the demands on the Controller(s) and the DIA, especially when dealing with emergencies or difficulties. it would be impossible to abandon the tasks in which they were engaged explicitly to provide information to each other as to what they were doing and why. And yet it is essential that both Controller and DIA remain sensitive to each other's conduct, not only to allow them to coordinate specific tasks and activities, but also enable them to gather the appropriate information to grasp the details of the current operation of the service." (Heath and Luff, 1992, p. 74).

Heath and Luff (p. 75) provides a striking example of tacit development of reciprocal awareness:

	… Controller calls Driver …
Controller:	Control to the train at Charing Cross South Bound, do you receive?
	… Controller switches monitor to the platform …
Controller:	Control to the train at Charing Cross South Bound, do you receive?
Driver:	Two Four O Charing Cross South Bound
Controller:	Yeah, Two Four O. We've got a little bit of an interval behind you. Could you take a couple of minutes in the platform for me please?
Driver:	(( )) Over
Controller:	Thank you very much Two Four O.
DIA:	Hello and good afternoon Ladies an Gentlemen. Bakerloo Line Information…

"The announcement emerges in the light of the DIA overhearing the Controller's conversation with the driver and assessing its implications for the expectations and experience of travellers using the service. He transforms the Controller's request into a relevant announcement by determining who the decision will effect and its consequences. In this case, this is particularly the passengers at Charing Cross whose train is delayed as a consequence of a problem emerging on the Southbound service. […] The DIA does not wait until the completion of the Controller's call before preparing to take action. Indeed, in many cases, it is critical that announcements are delivered to passengers as Controllers are making adjustments to the service. In the case at hand, as the call is initiated, we find the DIA progressively monitoring its production and assessing the implications of the Controller's request for his own conduct. The technology, and in particular the fixed line diagram, provides resources through which the DIA can make sense of the Controller's actions and draw the necessary inferences. At the onset of the call he scans the fixed line diagram to search for an explanation, or provide an account for, why the Controller is contacting a driver and potentially intervening in the running of the service. By the Controller's second attempt to contact the driver, the DIA is moving into a position at the console where he will be able to reach the operating panel for the Public Address system and if necessary make an announcement. On the word 'couple', at which point he can infer the potential delay that passengers might incur, he grabs the microphone and headset in preparation for the announcement. In consequence, even before the Controller's call to the driver is brought to completion, the DIA has set the Public Address system to speak to the passengers on a particular platform and is ready to deliver the announcement." (Heath and Luff, 1992, pp. 75 f.)

In the example given above, the DIA's very looking for evidence is motivated and driven by virtue of the Controller's attempt to call a driver:

"Activities such as telephone conversations with personnel outside the room, tracking a particular train with the CCTV, or discussions with Line Management concerning the state of the service, are, at least in part, publicly visible within the local milieux and ordinarily the bits and pieces available can be used to draw the relevant inferences." (Heath and Luff, 1992, p. 79)

Having noticed the Controller's attempt to call a driver, the DIA scans the fixed line diagram in order to provide an account for the upcoming intervention. That is, the DIA is not only able to overhear the Controller and assume that they have mutual access to the same information displays, but is also able to discern, through "peripherally monitoring the actions of his colleague", where the Controller might be looking and what he might have seen. "The various information displays, and their use by particular individuals, is publicly visible and can be used as a resource in determining courses of action and for the mutual coordination of conduct." (p. 76)

For the operators to make sense of what each other is doing, the activities of the other must be interpreted in relation to the state of the field of work. Thus, the formation of the reciprocal awareness requires access to (much of) the same evidence regarding the current state of the field of work (the movement of trains, passengers etc.): "The fixed line diagram and the station monitors, provide an invaluable resource for the DIA in producing an account for his colleagues' interventions in the running of the service" (p. 76). In particular, the common availability of various sources of information in the Line Control Room allows the DIA to assume that the current problems in the operation of the service noticed by the Controller are similarly available to the himself if he scans the various displays.

> "The 'public' availability of the technology within the Control Room, whether it is a fixed line diagram, a CCTV screen, a screen-based line diagram or an information display, and the visibility of its use, provide critical resources in the collaboration between Controller and DIA. [...] More importantly perhaps, the DIA and Controller can use the common sources of information as a reliable means of accounting for a broad range of actions and tasks undertaken by the other. [...] Moreover, their use of the fixed line diagram and the surrounding monitors of the console is publicly visible, and can be used to determine a particular activity in which the DIA or Controller is engaged, or, [...] to display a potential problem which is emerging within the operation of the service. The mutual availability of the various information displays, and the visibility of their use, are important resources for making sense of the actions of a colleague and developing a coordinated response to a particular incident or problem." (Heath and Luff, 1992, p. 76)

Now, the formation of reciprocal awareness is not only the product of a — more or less — passive (visual and auditory) monitoring of what others are doing but involves the complementary pro-active process of conveying cues of one's own activities and concerns. Thus, where activities (such as reading the timetable or entering the details of incidents on the various logs) are less visible, the details of the activity may not be readily available to a the others. Making such 'less visible' activities accessible to colleagues may for example involve reading or thinking aloud, humming, and so forth. The London Underground case provides an excellent example of how one operator actively directs the attention of another to some particular feature of the state of the field of work in a way that is more direct and effective than merely marking certain objects but still unobtrusive and inconspicuous:

> "On occasions, it may be necessary for the Controller to draw the DIA's attention to particular events or activities, even as they emerge within the management of a certain task or problem. For example, as he is speaking to an operator or signalman, the Controller may laugh or produce an exclamation and thereby encourage the DIA to monitor the call more carefully. Or, as he turns to his timetable or glances at the fixed line diagram, the Controller will swear, feign momentary illness or even sing a couple of bars of a song to draw the DIA's attention to an emergent problem within the operation of the service. The various objects used by the Controller and DIA to gain a more explicit orientation from the other(s) towards a particular event or activity, are carefully designed to encourage a particular form of co-participation from

a colleague, but rarely demand the other's attention. They allow the individual to continue with an activity in which they might be engaged, whilst simultaneously inviting them to carefully monitor a concurrent event." (Heath and Luff, 1992, p. 81)

Now, in spite of the enormous flexibility, efficiency, and effectiveness of these informal and implicit modes of interaction, the coordination of the myriad activities of the Bakerloo Line *at large* is far too complex, far too distributed in space and time, and involves far too many actors and specialties to be managed by means of these modes of interaction. These large-scale cooperative activities are basically managed by means of a timetable:

"The Underground service is coordinated through a paper timetable which specifies: the number, running time and route of trains, crew allocation and shift arrangements, information concerning staff travel facilities, stock transfers, vehicle storage and maintenance etc. Each underground line has a particular timetable, though in some cases the timing of trains will be closely tied to the service on a related line. The timetable is not simply an abstract description of the operation of the service, but is used by various personnel including the Controller, DIA, Signalmen, Duty Crew Managers, to coordinate traffic flow and passenger movement. Both Controller and DIA use the timetable, in conjunction with their understanding of the current operation of the service, to determine the adequacy of the service and if necessary initiate remedial action. Indeed, a significant part of the responsibility of the Controller is to serve as a 'guardian of the timetable' and even if he is unable to shape the service according to its specific details, he should, as far as possible, attempt to achieve its underlying principle: a regular service of trains with relatively brief intervening gaps." (Heath and Luff, 1992, pp. 72 f.)

The timetable requires continuous management by the operators:

"The timetable is not only a resource for identifying difficulties within the operation of the service but also for their management. For example the Controller will make small adjustments to the running times of various trains to cure gaps which are emerging between a number of trains during the operation of the service. More severe problems such as absentees, vehicle breakdowns or the discovery of 'suspect packages' on trains or platforms, which can lead to severe disruption of the service, are often successfully managed by reforming the service. These adjustments are marked in felt pen on the relevant cellophane coated pages of the timetable both by the Controller and the DIA, and communicated to Operators (Drivers), Signalmen, Duty Crew Managers and others when necessary." (Heath and Luff, 1992, p. 73)

"Perhaps the most critical activity within the Line Control Room [...], is rewriting the timetable; a process known as 'reforming' the service. Almost all problems which arise in the operation of the service necessitate 'reformations', where the Controller, actually within the developing course of an event, reschedules particular trains, their crews, and even their destination, so as to maintain, for the practical purposes at hand, a relatively even distribution of traffic along the line." (Heath and Luff, 1992, p. 79).

However, as opposed to changes to the state of the field of work as represented by the fixed line diagram or the platform monitors, changes made to the timetable are not immediately and automatically conveyed to the other operators. The distributed management of the timetable may therefore give rise to inconsistencies in the cooperative operation of the line. In this case, the Controller handles this by thinking aloud when his is making changes to the timetable:

"It is essential that both colleagues within the Line Control Room, and personnel outside such as Duty Crew Managers, drivers and even Station Managers, are aware of these changes. Otherwise, these staff will not only fail to enact a range of necessary tasks, but will misunderstand the state of the service and make the wrong decisions. Reforming the service however, is an extremely complex task, which is often undertaken during emergencies, and it is not unusual for the Controller to have little time explicitly to keep his relevant colleagues informed.

One solution to this potential difficulty is to render features of their individual reasoning and actions 'publicly' visible by talking though the reformations whilst they are being accomplished. The Controllers talk 'out loud', but this talk is not specifically directed towards a colleague within the Control Room. Rather, by continuing to look at, and sketch changes on the timetable, whilst producing talk which is often addressed to oneself, the Controller precludes establishing a 'recipient' and the interactional consequences it would entail. Talking through the timetable, whilst rendering 'private' activities 'publicly' visible, avoids establishing mutual engagement with colleagues which would undermine the ongoing accomplishment of the task in question. Consider the following fragment in which the Controller finishes one reformation and then begins another.

	*…Controller **reads** his timetable …*
Controller:	It's ten seventeen to ( ) hhhhhhh
	(4.3)
Controller:	Right (.) that's that one done.
Controller:	hhh hhh (.) hhh
Controller:	Two O Six ( ) Forty Six
	(0.7)
Controller:	Two Two Five
	… the DIA begins to tap on his chair and the trainee begin a separate conversation. As they begin to talk the Controller ceases talking our loud …

Whilst looking at the timetable, the Controller announces the completion of one reformation and begins another. The Controller talks numbers, train numbers, and lists the various changes that he could make to the 206 to deal with the problems he is facing, namely reform the train to ~46 or to 225. As the Controller mentions the second possibility, the DIA begins to tap the side of his chair, and a moment or so later, discusses the current problems and their possible solutions with a trainee DIA who is sitting by the DIA's side. As soon as the DIA begins to tap his chair and display, perhaps, that he is no longer attentive to his colleague's actions, the Controller, whilst continuing to sketch possible changes on the timetable, ceases to talk out loud. Despite therefore, the Controller's apparent sole commitment to dealing with specific changes to the service, he is sensitive to the conduct of his colleague, designing the activity so that, at least initially, it is available to the DIA and then transforming the way the task is being accomplished so that it ceases to be 'publicly' accessible.

Whilst 'self talk' may primarily be concerned with providing co-present colleagues with the necessary details of changes made by the Controller to the running order of the service, it is interesting to observe that a great deal more information is made available in this way than simply the actual reformations. […] [T]he Controller renders visible to his colleagues the course of reasoning involved in making particular changes. The natural history of a decision, the Controller's reasoning through various alternative courses of action, are rendered visible within the local milieu, and provides colleagues with the resources through which they can assess the grounds for and consequences of 'this particular decision' in the light of possible alternatives. While the Controller is talking out loud, it is not unusual to find the DIA following the course of reasoning by looking at his own timetable, and where necessary sketching in the various changes which are made. In this way, DIA and Controller, and if present, trainees and reliefs, assemble the resources for comprehending and managing the service, and preserve a mutually compatible orientation to the 'here and now', and the operation of the service on some particular day. The information provided through the various tools and technologies, including the CCTV monitors, the fixed line diagram, and information displays, is intelligible and reliable by virtue of this collaborative activity." (Heath and Luff, 1992, pp. 79-81)

In sum, then:

(1) The field of work of the operators in the Bakerloo line control room, i.e., the trains and the infrastructure of the line on one hand and the passengers on the other, is not causally coupled in the same strict sense as the hot rolling mill and the nuclear power plant. Rather, the general function of the line operators is to establish a very close coupling of the movement of trains and passengers so as to provide the required quality of service to the passengers.

(2) The various information displays, and their use by particular individuals, are publicly visible and can therefore be used as a resource in determining courses of action and for the mutual coordination of conduct. The operators can use the common sources of information as a reliable means of accounting for a broad range of actions and tasks undertaken by the other. The mutual availability of the various information displays, and the visibility of their use, are important resources for making sense of the actions of a colleague and developing a coordinated response to a particular incident or problem.

(3) The operators do not regulate the state of the field of work by means of effectors or other control mechanisms. Rather, they regulate the state of the field of work by means of talking with train drivers, station managers, and passengers via radio and telephone. Accordingly, the two operators can develop and maintain a more rich and accurate reciprocal awareness by overhearing each other's conversations over telephone or radio.

(4) The operators direct the attention of their colleague to certain features or events in myriad ways: by modulating their conversations with third parties, by humming or singing, by gazing etc.

(5) The large-scale cooperative operation of the Bakerloo Line as a whole is basically managed by means of a timetable. To serve this coordination purpose, the timetable requires continual management by the operators. This management of the timetable is itself a cooperative activity whose articulation may require the application of the whole repertoire of modes of interaction.

3.2. Air traffic control

A comprehensive study on cooperative work in air traffic control conducted over several years by researchers at the Department of Sociology at the University of Lancaster has provided interesting insights into the delicate and multifaceted handling of an artifact — the flight strip — to facilitate fluent and dynamic articulation work (Hughes et al., 1988; Harper et al., 1989a; Harper et al., 1989b; Harper et al., 1991; Hughes et al., 1992; Harper and Hughes, 1993; Hughes et al., 1993).

The whole of the airspace of England and Wales is controlled from a center near London. In order to handle the complexity of ensuring orderly and safe air traffic, the airspace is divided into sectors. Thereby, a moderate degree of coupling of the system has been achieved (Perrow, 1984, pp. 159 f.).

The capacity of a given sector is determined by the workload limit of controllers. On the other hand, a further subdivision of the airspace into a larger number of smaller sectors may not be feasible, due to the increased overhead of coordination activities that would entail. Operators controlling different sectors are interdependent in their work in that the state of one sector will have consequences for the state of an adjoining sector and vice versa (Harper et al., 1989a, p. 5). As the number of sectors increases, so too do the coordination and handover elements of the workload, so that the potential gain is negated (Hughes et al., 1988, pp. 33 f.).

Two types of sectors are distinguished. The *en route* sectors are the 'lanes' between major junctions of the airways. Thus, the bulk of traffic is *en route* to somewhere beyond the sector. By contract, Terminal Maneuvering Areas (TMAs) are sectors at the confluence of major airways and over busy airports.

The majority of aircraft travel through a sector only for an average of 20 minutes at a time. On busy *en route* sectors there can be up to 30-40 planes an hour. The speed of modern jet aircraft means that air traffic controllers have to make decisions quickly to maintain adequate separations; decisions that, regularly and routinely, have to deal with various departures from standard profiles, such as failure to achieve expected levels and pilots mishearing instructions. However, even under ordinary controlling conditions, air traffic control has a *discretionary character* (Hughes et al., 1988, pp. 19 ff.):

The objective of air traffic control is to direct flights safely and efficiently to their destinations. Safety is basically attained by keeping aircraft separated from each other, and the standard distances for this are five miles laterally and 1,000 feet vertically. Efficiency, on the other hand, is attained by directing aircraft to follow the shortest available route. Unavoidably, there is an occasional conflict between these two aims and it is up to the controllers to maintain the first by sometimes compromising the latter using the procedural framework of the Air Traffic Control system. Hence the discretionary character of ATC work: The "implementation of the rules of control consist in working within them with respect to a particular configuration of aircraft at any one time; a configuration that may be, as it were, 'typical' but which may also display 'untypical' and unpredictable characteristics." (Hughes et al., 1988, p. 20). The specific complexity of air traffic control as a work domain, then, is a function of the potential risk of midair collisions, the time-constraints under which decisions must be taken, and the number and configuration of aircraft in the air.[9]

The complexity of controlling a sector is not primarily related to the number of aircraft in the sector but rather to the specific "configuration" of the sector:

9 "In ATC processing delays are possible; aircraft are highly maneuverable and in three-dimensional space, so an airplane can be told to hold a pattern, to change course, slow down, speed up, or whatever" (Perrow, 1984, p. 160).

> "Although there is a limit to the total number of aircraft a controller can handle at once, it is the configuration of those aircraft which is the more important feature attended to in controlling. Roughly speaking, the more complicated that configuration — with cross-overs, planes ascending and descending, changing direction, and so on — the more difficult is coordination." (Hughes et al., 1988, p. 20).

Controlling a sector requires the cooperative effort of several operators. Thus, each sector is normally, that is when traffic is relatively light, controlled by a team consisting of two air traffic controllers, two assistants, and one sector chief. During busier periods, sectors may be split according to the intensity and the complexity of the traffic. On the other hand, when traffic is very light, usually at night, the two sides of a sector may be controlled by only one controller under the supervision of a chief and with the help of another controller or 'wingman' (Hughes et al., 1988, pp. 104 f.). Air traffic control thus requires cooperative work arrangement with an elaborate and dynamically changing system of division of labour. .

The control of any one sector is executed at a particular "suite", i.e., a workstation equipped with radar screens, telephone and radiotelephone communication facilities, maps, computer input and printout stations, and racks for flight progress strips. (See Figure 8).

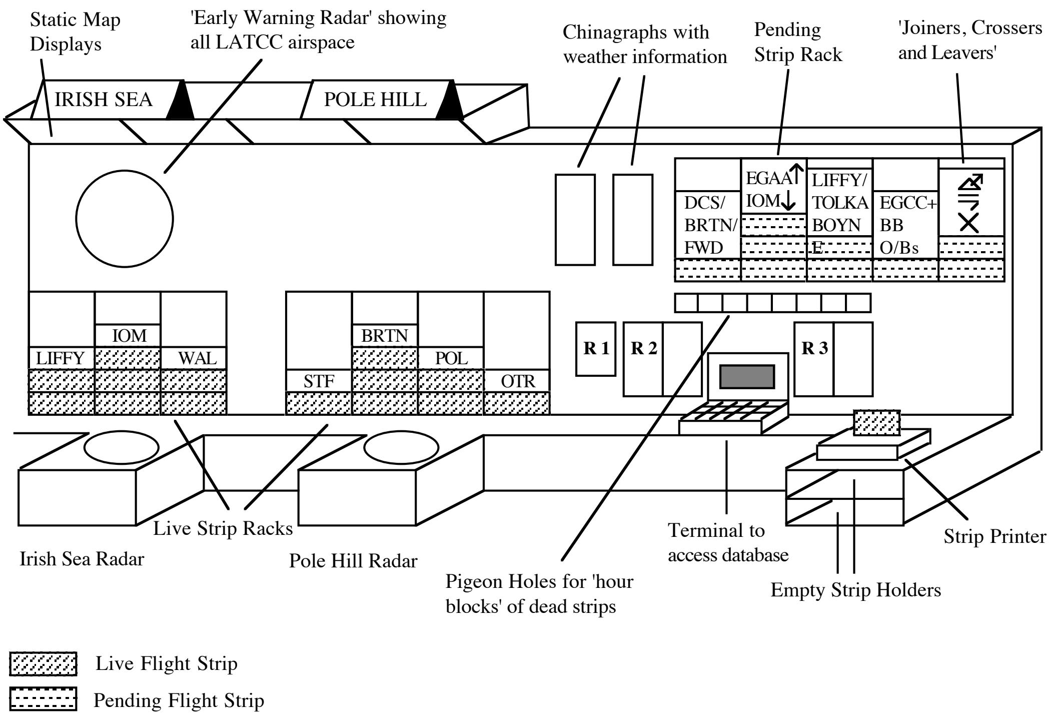

Figure 8. Layout of an en-route suite: Pole Hill and Irish Sea sectors. (Hughes et al., 1992)

The radar system, in addition to representing radar contacts as 'blips', displays a 'data block' alongside each blip showing the flight number and flight level of the aircraft (based on data provided by the responder of the aircraft). Furthermore, some screens display a trail of 'blips' representing the heading of each particular flight. The radar system is used to provide “an accurate representation of movement in airspace”, that is, a representation of the current state of the field of work at any moment. “Cognitively, the screen is a technological representation of a slice of sky and the relevant events occurring within it. The orderliness of the screen stands proxy for the orderliness of the sky ” (Hughes et al., 1988, p. 40).

However, the radar screen is uninterpretable without the further information for each flight embodied in the flight progress “strips”, especially “the goals, intentions and plans of pilots and controllers and their recent actions” (Harper et al., 1989a, p. 10□). The strips are made of card, approximately 200 by 25 mm and divided into fields (see Figure 9). The information in the fields comes from a database holding the flight plan filed by the pilot prior to departure, sometimes modified by inputs keyed in by controllers or assistants. It includes the aircraft’s callsign, its flight level, its heading, its planned flight path, the navigation points on its route and estimated time of arrival, the departure and destination airports, and the aircraft’s type. Strips are arranged in racks immediately above the radar screens. The racks are in turn divided into bays, separated by fixed markers representing particular navigation points in the sector.

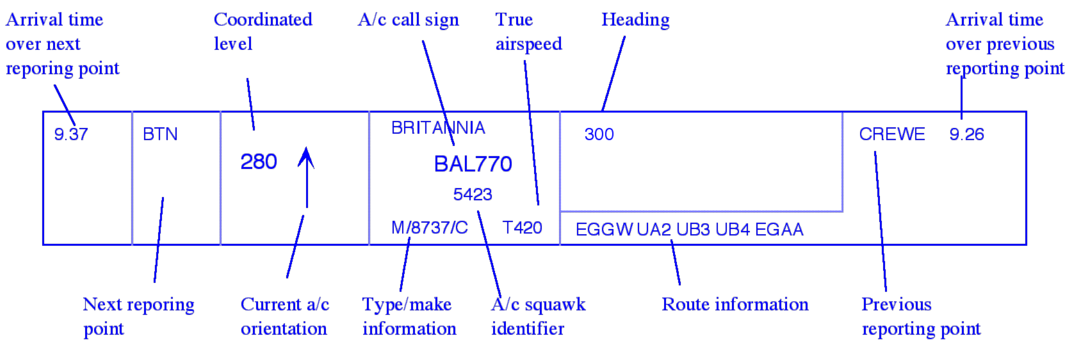

Figure 9. A flight progress strip. (Graphics made by the author on the basis of a photocopy of a specimen provided by the Lancaster group).

A strip first comes to the attention of the controller when it is placed on the strip bay. New strips are initially treated as ‘pending strips’ and placed above a special strip denoting the navigation point marking the boundary of the sector. Once the aircraft in question calls the controller, the relevant ‘pending’ strip is placed beneath the marker strip. It is now ‘live’. The collection of pending strips enables a controller to gauge at a glance what traffic is due in the sector and, consequently, how busy he or she is likely to be, either because of the number of strips stacked or the complexities indicated. For example, “noting among the ‘pending strips’ a fast aircraft curving along a route but not yet entering the sector in which there is already a slower aircraft, and therefore the possibility of an overtaking problem, is to use the ‘pending’ strips to *see* ‘the state of the sector’ *now* in terms of the likely problems ‘in a few minutes time’.” (Harper et al., 1989a, p. 13). Pending strips are thus part of the controller’s “horizon of attention” in the sense that it “incorporates the future in relation to the present ‘state of the sector’”

(Harper et al., 1989a, p. 40). The controller will mark the pending strips for any features deemed appropriate to note, such as aircraft speed, route and airway, destination, or whatever. The strips may be ordered according to their pending times and strips indicating a procedural conflict may be lifted slightly out of position ('cocked out').

Because of the potential risks involved, the time-critical nature of the control task, and the exigencies of traffic flow, the overriding concern of air traffic controllers is to organize their work in such a way that they provide themselves with 'thinking time' so that when there is least 'thinking time' there will be 'least to think about' (Harper et al., 1989a, p. 11). Thus, pending strips are organized in such a way that they are "made relevant" to what the controller anticipates will happen and plans to do in what order and with what priority:

> "Ordering the strips is […] a way of shaping attention in terms of the particularities that make up the 'current state of the sector' including such matters as traffic densities, standard traffic patterns, and any special problems such as VIP flights that need to be anticipated. This preliminary ordering of the strips is not determinatively related to real time events 'in the sky' as represented on the radar screen since, at this stage, the aircraft referred to by the strips are 'not yet the business of this sector controller'. This is very much a preparatory, but vital, ordering." (Harper et al., 1989a, p. 17).

By contrast, the revision of live strips is seen as organizing what the controller is immediately about. The revisions on live strips are not noticings of what is likely to be the case but records of what has been done. When a controller gives an instruction to a pilot, for example to ascend to flight level 220, he or she marks this on the strip. In this case, the mark is an upwards arrow and the number 220. When the pilot acknowledges the instruction, the controller crosses through the old flight level on the strip. When the new flight level is attained, the controller marks a check beside it. Changes in heading, estimated time of arrival, route, call sign, etc. are recorded in similar ways. The information contained on the strip is thus systematically altered as instructions given and acknowledged or as up-dates on aircraft now being dealt with. "In this manner not only is the 'state of the sector' displayed and seeable 'at a glance' by those equipped to read the strips, but a written, and reproducible, record of actions taken is created" (Harper et al., 1989a, pp. 14 f.). Or in the words of one of the controllers interviewed by Harper and associates, strips "are like your memory, everything is there" (p. 49).

As opposed to radar, strips are not an automatically updated representation of the state of the sector. Nor do strips "determine the sequence of tasks controllers perform" in the same way as the activities of the operators of the hot rolling mill are subjected to a rigorous temporal order:

> "Although the strips are produced according to the order in which designated aircraft will reach defined markers, the controller has to organize the strips so that they can become an instrument that serves, and makes possible, controlling work. Strips are 'manipulated', 'taken note of', 'ignored for the moment', 'revised', and more, continuously throughout the time that they are in use." (Harper et al., 1989a, p. 16).

Strips are organized and annotated according to a standardized format:

- The categories of information on the strip and its general typographical layout follow a standard format.
- The color of the strip holder is used to effect a two-fold categorization into east and west bound traffic.
- The color of the strip paper is used to effect a two-fold categorization into 'standard' and 'crossing' or military traffic.
- The color of hand notations on the strip is used to effect a two-fold categorization distinguishing annotations made by the controller from annotations made by the sector chief.
- In general, annotations follow an elaborate set of conventions specified in the *Manual of Air Traffic Services* (e.g., upward or downward arrows, check marks, crosses through numbers).

Because of their "formatted character", "strips provide a *template* for noting and recording what is happening and will happen in the sector." (Harper et al., 1989a, pp. 15 f.). More than that, also because of their "formatted character", strips serve as a resource for articulating the activities of the different members of the sector team. In maintaining a constantly up-dated representation of the 'state of the sector' in terms of the standard categories of information on the strip itself and in the standard format and notation, the controller is not just providing information relevant to his or her own work but is also providing what Harper and associates calls "team relevant information":

> "The conventionality of the strips, their standard format, the known-in-common notations used, make the work the strips represent visible, in *multi-functionalities*, to other members of the sector team, other controllers, chiefs, assistants, etc.; in fact, to anyone enculturated in the work of controlling. In making manifest 'actions so far' in ways that are 'seeable at a glance' by those equipped and needing to know, the strip plays a key role in the team features of the social organisation of controlling work." (Harper et al., 1989a, pp. 15 f.)

The strip thus serves as a 'note pad' for all the team members, any of whom may write on it. "The standard format of data, colour coding of holders, role distinctive markings, the placement of the racks, among other features, means that, again 'at a glance', what the strip signifies in terms of controlling tasks is available to other members of the team" (Harper et al., 1989a, p. 45).

Thus, while being an important means of anticipating and controlling the state of the field of work as a whole, the strips in their racks simultaneously play a crucial role in the articulation of the work of members of the sector team. Controllers do not just attend to their 'own' strips but regularly read the strips, both pending and live, that 'belong' to their suite colleagues. Rather than being read closely, strips of colleagues will be read 'at a glance' to see if anything is indicated which might be of concern. This activity is related to 'buying time' by expanding the horizon of attention for a moment to obtain wider coverage. This tacit monitoring also enables the controller to asses how busy the colleague is and whether coordination can be achieved easily.

When necessary, overt coordination can be achieved by pointing to particular strips where there may be a problem, perhaps two flights due at the same navigation point at a similar time and at the same height. If the controller cannot attend to the request at that time, anyone who notices the problem can "cock out" the strips, i.e., move them noticeably out of alignment in the racks. In a very inconspicuous and non-intrusive way, this makes it immediately obvious that, when it is time to deal with those flights, a problem will need to be considered, and to the practiced eye it will be obvious from a glance at the strips what the problem is (Hughes et al., 1992). "Such *noticings* do not need to specify just what specifically the problem might be; simply marking out the strip as 'something to take note of' is normally sufficient." (Harper et al., 1989a, p. 24).

The facility with which controllers can tacitly monitor each other's strips and each other's work with strips is, of course, "a function of the adjacent positioning" of the controllers on the suites. "This means that alterations or reference to strips 'on the other side' can be done with a minimum of explanation. [...] Drawing the strip slightly out of position, pointing to it, making a notation, are 'sufficient' to draw attention to *that* strip, and its aircraft, and any problem it may represent and, as such, are actions manifesting the interdependence of one controller's activities with those of others." (Harper et al., 1989a, p. 24).

In providing means for representing the division of labour on the suite ("the conventional notations used denoting not only actions taken but by whom"), the 'formatted character' of flight strips provides yet another mechanism for articulating the cooperative effort of controlling a sector of airspace.

> "Alterations, whether by controllers or by the chief, are 'instantly' recognisable as alterations by 'such-and-such' and, therefore, informative about the kind of problem the 'noticing' might represent. So, the distinctiveness of markings on the strips, by calling into play the division of labour of controlling, also guides the attentiveness that makes the information as information to be 'noted and dealt with accordingly'." (Harper et al., 1989a, p. 27)

In sum, then:

(1) The regulation of the field of work of a particular sector team — i.e., the regulation of the sector and its changing configuration of aircraft — is done by means of radiotelephone communications with pilots. As in the case of the London Underground control room, the different operators at the suite can thus develop and maintain a reciprocal awareness of each other's activities by overhearing each other's conversations with actors 'in the field'.

(2) Each member of the sector team is able to interpret the activities of the others because the state of the field of work as represented by the radar displays and the ordered collection of annotated flight strips is publicly available to all members of the team.

(3) The flight strip is a vehicle for making activities persistently and publicly accessible by recording pertinent actions in the course of a flight through the sector. The flight strip supports and mediates the articulation of the work of the sector team, not only because of its public visibility, but also and most importantly because of its formatted character.

(4) Embedding cues in the objects belonging to or representing certain objects in the field of work, e.g. by highlighting certain flight strips (cocking out) is an

non-intrusive and tacit way of directing attention. On the other hand, the expressive power of materially embedded cues is limited. In the case of the flight strips, the 'categorical distinction' supported by highlighting strips is "effectively limited to two categories", namely relatively routine versus relatively problematic (Harper et al., 1989a, p. 30).

3.3. Portfolio management

A portfolio management agency investigated by the author in 1987 (Schmidt, 1987) provides an simple example of the use of simple artifacts as vehicles of articulation work and of the cooperative effort required to manage the artifact.

Investors are faced with an extremely complex and turbulent object domain — the world market, or rather the complex of interrelated national and international markets for bonds, shares, options, futures, currencies, commodities, etc. Portfolio management agencies assist clients in making sound investment decisions, monitoring the state of their portfolios, and taking corrective actions as need be.

Portfolio management can thus be conceived of as a mediating function between a number of clients with different individual propensities and concerns on one hand and on the other hand an extremely complex and turbulent object domain.

That is, on one hand portfolio management is faced with the monitoring and navigating the vast space of potential investment objects and their multi-dimensional interdependencies:

- Kinds of markets: shares, bonds, futures, options, currency, etc.
- National economies with different currency rates, interest rates, inflation rates, political prospects, etc.
- Branches of production with different technical developments and market trends.
- Relations of ownership and control.

On the other hand, the different characteristics of clients add to the complexity of portfolio management:

- Clients have specific propensities and apprehensions.
- Clients have different 'risk profiles'.
- Clients have different needs for liquid assets.

In order to handle this complexity, the portfolio management agency studied by the author has adopted a fairly clear division of work and responsibility between 'analysts' and 'consultants' that reflects the polarity of the field of work. The analysts monitor the development of the markets in order to identify new investment opportunities as well as to monitor the changing degree of risk exposure of current investments, whereas the consultants monitor and control the individual portfolios in accordance with the propensities and concerns of their clients: they will sell and buy in order to keep the profile of the portfolio in line with that of the client.

Also in order to handle the compelling complexity, the portfolio management agency in question has developed effective strategies for reducing operational complexity.

As far as the complexity posed by the multiplicity of clients' propensities is concerned, the multiplicity is reduced drastically by classifying clients according to a very simple classification scheme:

- Risk profile, with only three categories: 'speculative', 'medium', 'conservative'.
- Needs for liquid assets, again with only three categories: 'high', 'medium', 'low').
- Specific commandments (e.g., 'No South African shares').

The complexity of controlling that the composition of each portfolio at any time is in accordance with the client's profile can thus be reduced to a relatively simple daily routine:

- The different needs for liquid assets can be attained by establishing and maintaining a certain mixture of high-volume bonds, low-volume bonds, and shares.
- The risk profile of the client can be translated directly into a corresponding mixture of shares of different risk categories ('speculative', 'medium', 'conservative').
- In addition, accordance with the client's risk profile can be ensured by distributing the investments of each portfolio over a number of countries and branches.

As far as the immense complexity posed by the markets is concerned, the portfolio management agency in question has drastically reduced the number of potential investment objects to be taken into account on a daily basis by maintaining a 'positive list' of approved shares. This list comprises some 200 shares which are deemed 'interesting' and 'attractive'.

In the daily routine of portfolio management, i.e., in monitoring and regulating the composition of each portfolio, the consultants only buy shares that have been approved and added to the list. Because the list — as a written text — is persistently accessible, a lot of time consuming and disruptive discourse between analysts and consultants is avoided. Though a very simple artifact, the list substantially reduces the overhead cost of conveying the recommendations of the analysts to the consultants.

However, taking investment decisions on behalf of a client is a delicate affair. A certain anxiety prevails. This issue is exacerbated when, as is the case in the particular portfolio management agency in question, clients typically are institutional investors and other large investors who often possess considerable insight of their own in the workings and behavior of the markets. The overriding concern of the consultants, therefore, is to be able to 'explain' and 'justify' their actions to their clients. Accordingly, a continual exchange of views and background information between analysts and consultants is a prerequisite for the consultants' ability to instill confidence in their clients. For instance, the consultants need to be able to explain to clients how the markets in which they have invested behave; they must be able to tell whether there are causes for concern; they must be able to inform the client of his position; and they must be able to discuss alternative options. Thus t situation in the markets is discussed regularly across the room. That is, a close contact between analysts and consultants is necessary.

This need for access to background information applies to the list as well. If the consultants simply had to execute a list handed down from analysts at the headquarters of the bank,[10] they would not be able to instill much confidence in their clients. The list is therefore managed cooperatively by the analysts and consultants in the sense that the analysts has to convince the consultants of the rationality of any change to the list whereas the consultants, reflecting the concerns of their clients, so to speak play stubborn and recalcitrant. The recommendations of the analysts are only accepted after intensive and thorough discussion. In fact, quite often the cooperative management of the this simple coordination mechanism will turn into protracted and heated arguments.

In sum, then:

(1) Day-to-day decisions concerning the control of portfolios are made on the basis of a list of ca. 200 ‘approved’ shares. As an artifact, the list is quite unassuming. It does not provide any structure to the listed shares. The list merely records and conveys the fact that the listed shares have been agreed upon as ‘interesting’ securities.

(2) The list mediates and coordinates cooperative work between specialists in the sense that the daily portfolio control work of the consultants can be carried out without ongoing discourse with the analysts.

(3) However, the management of the list itself is a cooperative activity. Since the consultants need to be able to ‘explain’ their actions to their relatively sophisticated clients, approval of the composition of the list requires — sometimes heated — debates between analysts and consultants. In other words, the cooperative management of the list involves negotiation.

(4) In fact, continual exchange of views and background information between analysts and consultants is a prerequisite for the consultants’ ability to instill confidence in their clients.

(5) That is, given the fact that the clients of the portfolio management agency in question are relatively sophisticated, the division of labour between analysts and consultants is feasible if and only if the consultants have access to general background information about the state of affairs in the markets and the rationale for selecting particular securities as investment objects for certain clients.

(6) The discretionary nature of investment decision making combined with the general anxiety of managing other people’s fortunes and the exacerbated stress of serving relatively sophisticated and demanding clients all conspire to require in-

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10 Which is what the headquarters of the bank planned to do at the time.

tensive daily contact and, intermittently, spontaneous debates and negotiations between analysts and consultants.

3.4. Modes of interaction

As illustrated by the case studies described above, articulation work involves an open-ended repertoire of interactional activities that are meshed fluently in innumerous ways. For example:

Maintaining reciprocal awareness: The articulation of the distributed activities in a cooperative setting normally requires the continuous formation among the members of the cooperating ensemble of a reciprocal awareness of the activities, concerns, and intentions of the other members of the ensemble. Or in the words of Heath and Luff: "The ability to coordinate activities, and the process of interpretation and perception it entails, inevitably relies upon a social organisation; a body of skills and practices which allows different personnel to recognise what each other is doing and thereby produce appropriate conduct." (Heath and Luff, 1992, pp. 70 f.)

The development and maintenance of reciprocal awareness of the work of the other members of the ensemble may involve an ongoing process of inconspicuous, unobtrusive, and even "surreptitious" (Heath and Luff, 1992, p. 74) monitoring of the activities of the others, by seeing and hearing what the others are doing, where they are in the room; by noticing the level of letters in the in-box or the lack of certain parts in racks containing the buffer stock, and so on.

The formation of reciprocal awareness through monitoring of the activities of the others is matched by an 'inverse' — and often equally inconspicuous and unobtrusive — effort of rendering activities visible to the others: modulating operations on the field of work, humming, thinking aloud, leaving traces, recording, logging, reporting, etc.

Directing attention: In articulating their joint effort, each of the members of the cooperative ensemble may deliberately — but not necessarily consciously — direct the attention of the other members to certain features of the state of the field of work, a possible problem, disturbance or danger, etc. by invoking a multitude of interactional activities:

- by embedding cues, e.g., by marking particular items, for instance by positioning them in certain locations and ways, by highlighting them, etc.
- by tacitly modulating work activities in uncommon, unusual, or abnormal ways;
- by gingerly humming, drumming, coughing, gazing;
- by overtly pointing, nodding etc. at particular objects;
- by warning explicitly (talking, shouting, annotating, writing).

Assigning tasks: As pointed out by Strauss, a wide variety of social modes of task allocation can be observed:

> "tasks can be imposed; they can be requested; also they can just be assumed without request or command; but they can also be delegated or proffered, and accepted or rejected. Often they are negotiated. And of course actors can manipulate openly or covertly to get tasks, or even have entire kinds of work allocated to themselves." (Strauss, 1985, p. 6.)

Moreover, tasks can be requested in countless ways: by nodding towards a thing, by highlighting an object of work, for instance by it at a certain spot (in the in-box, on the desk, pigeon hole), by explicit verbal request (post it note, office memo, executive command).

Handing over: In the course of a cooperative effort, responsibility for a certain process in the field of work may be handed over from one actor to another. Again, this can be done in different ways: the object itself may be handed over (e.g., the strip being passed on between operators of the hot rolling mill, parts being passed on to the next station in manufacturing), the interface to the control system may be handed over (e.g., the wheel on the bridge of a ship), a symbolic representation may be passed on as a semaphore and so on.

The point to be made by way of these examples, is that the myriad interactional activities involved in cooperative work cannot be ordered according to any simple conceptual scheme. Instead, a limited number of salient modes of interaction can be abstracted:

(1) Unobtrusive versus obtrusive: Interactional activities can be more or less obtrusive: some interactional activities such as pointing or tapping at an item or talking or shouting to colleagues are be highly intrusive in that they impose an obligation on the others to notice and react accordingly (more or less instantly). They therefore disrupt current activities (which may or may not be appropriate). Other interactional activities can be quite inconspicuous, such as, for example, embedding cues, humming, gazing, thinking aloud, leaving traces.

(2) Embedded versus symbolic: Embedding cues by highlighting particular items belonging to the field of work or representing the field of work, for instance by positioning them in conspicuous ways, at unusual locations or in abnormal orientations, by marking them etc., has significant advantages in that it (1) uses items that are ready-at-hand, perhaps ubiquitous, and that are constantly monitored due to their status as belonging to the field of work and (2) therefore is more efficient and less intrusive and distracting than, for instance, pointing or talking or other interactional activities that impose the role of a recipient on somebody.

Embedding cues in objects, for example by marking a certain feature in the field of work so as to convey to others that they should pay attention to a particular occurrence or take a particular action, is not, strictly speaking, a symbolic act. We are here following Peirce's distinctions:

> "In respect to their relations to their dynamic objects, I divide signs into Icons, Indices, and Symbols […]. I define an Icon as a sign which is determined by its dynamic object by virtue of its own internal nature. […] I define an Index as a sign determined by its dynamic object by virtue of being in a real relation to it. […] I define a Symbol as a sign which is determined by its dynamic object only in the sense that it will be so interpreted." (Peirce, 1901)

Thus, an artifact 'determined' by the field of work can be conceived of as having the function of an *index*: objects belonging to the field of work, means of data acquisition (e.g., sensors), representations that map the state of the field of work automatically (e.g., gauges, radar) or are made to represent the state of the field of work (e.g., flight strips).

The primary function of, for example, the flight strips is that of a representation of the state of the field of work, that is, of the current configuration of airplanes in the sector. The strip does not have the abstract nature that provides the degrees of freedom in its manipulation that otherwise makes *symbolic* representations so powerful. An individual flight strip should rather be seen as a *index* of a particular airplane — not in the sense that moving the strip will make the airplane move, of course — but in the sense that air traffic control relies predominantly and crucially on *the precise mapping* of the state of the airways onto the state of the strips so that any manipulation of the strip is subordinate to the objective of ensuring this mapping. That is, the repertoire of allowed operations on the flight strip is strictly limited by this primary function.

Any modulation of the way in which a strip is manipulated is therefore a sign embedded in the appearance of an artifact standing proxy for the state of the field of work. That is, the message is cloaked.

Interacting by manipulating some object or system belonging to or in an indexical relation to the field of work is a restricted way of interacting:

(a) The bandwith of embedded cues is limited to the degree of freedom offered by the role of the object in the field of work;

(b) the turn-around time of embedded cues may be limited by the frequency of state changes in the field of work;

(c) the message is garbled in that it is shrouded in the state of an object belonging to the field of work or representing certain features of the field of work.

On the other hand, the cases of the MRP II system and the kanban system, which will be discussed below, show the crucial importance, in some settings, of severing the (direct or automatic) coupling between the field of work and artifacts — namely when artifacts are used to stipulate and mediate the articulation of cooperative work. That is, such artifacts have to have a 'symbolic' status, as opposed to an indexical.

(3) Ephemeral versus persistent: A wide range of interactional activities are ephemeral in the sense that articulation work in these modes only exist in the flux of unfolding activities. For example,

- monitoring the activities of others, by seeing and hearing what the others are doing, where they are in the room; by noticing the level of letters in the in-box or the lack of certain parts in racks containing the buffer stock and so on;
- making one's own activities publicly visible by modulating operations on the field of work, humming, thinking aloud;

- directing attention by modulating work activities in uncommon, unusual, or abnormal ways, by humming, drumming, coughing, gazing, pointing, nodding, talking, shouting.
- allocating tasks by pointing, nodding, talking, shouting.

As soon as the articulation activities have been carried out and a new situation has arisen, the articulation that was achieved vanishes without trace, as it were — like the snows of yesteryear.

In important ways, the same applies to interactional activities that involve embedding cues. While certainly based on the use of artifacts, embedding cues depend on the fate of the items conveying the cues in the ever-changing field of work. The embedded cues may be erased by state changes, or they may not. As vehicles of embedded cues, the highlighted objects live an uncertain life.

Because of the immediate feedback and the ensuing possibilities of detecting and recovering from misunderstanding, combined with expressive power provided by the vast repertoire of modes that can be combined at any time, these modes of articulation offer immense flexibility in terms of articulating activities in face of the mundane and dramatic contingencies of cooperative work.[11]

These interactional modalities are especially crucial in cooperative work settings where articulation work is time-critical (as in the case of process control or air traffic control). Articulating cooperative activities in such settings typically requires a permanently open channel of communication with minimal turnaround time, for example by having the operators in the same room at the same time, so as to allow them to convey the multitude of inconspicuous cues that are required for cooperators to acquire and maintain reciprocal and general awareness of the changing state of affairs within the cooperating ensemble, as well as the field of work at large. Likewise, articulation of distributed activities that involve discretionary decision making — as in the case of portfolio management — will typically require, at least intermittently, various negotiation processes. For this purpose, conventional co-located 'face-to-face' interactions provide the required large bandwith, not only in terms of gigabits per second but also, and more importantly, in terms of a rich variety of interactional modes with powerful and flexible social connotations.

On the other hand, however, these ephemeral interactional activities do not provide strong support for making decisions and commitments concerning the articulation of cooperative work accessible to the members of the cooperating ensemble, independently of the situation, and independently of particular individuals or for supporting the development and implementation of stipulations for the ways in which in which cooperative work is to be conducted and articulated.

Written records (log books, recordings, minutes, memos etc.) provide persistence to decisions and commitments made in the course of articulation work: "The

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11 "In oral face-to-face settings, abundant non verbal cues and a common physical environment help establish a referential framework not usually available for written communication." (Goody, 1987, p. 268 — quoting Reder).

written language [reaches] back in time" (Goody, 1987, p 280). Written records are, in principle, accessible to any member of the ensemble, whatever its size and distribution in time and space. "Written systems can provide a larger number of people with the same information at one time." "Written messages are portable, allowing interaction without spatial constraints." On the other hand, "Written systems are much less dependent on physical arrangements" and "less time-dependent than oral systems." (Stinchcombe, 1974, pp. 50 f.).

As illustrated by the case of the list of approved shares in portfolio management, written artifacts can at any time be mobilized as a referential for clarifying ambiguities and settling disputes: "while interpretations vary, the word itself remains as it always was. (Though every reading is different, it is a misleading exaggeration of the literary critic to say that the text exists only in communication.)" (Goody, 1986, p. 6). However, and this is also illustrated by the portfolio management case, "written language is partly cut off from the context that face-to-face communication gives to speech, a context that uses multiple channels, not only the purely linguistic one, and which is therefore more contextualized, less abstract, less formal, in content as in form." (Goody, 1987, p. 287).

4. Mechanisms of interaction

As shown in the preceding discussion of modes of interaction, in much of everyday working life the required articulation of individual activities is managed effectively and efficiently by the rich variety of intuitive interactional modalities of everyday social life, so effectively and efficiently in fact that the distributed nature of cooperative work is not manifest, most of the time. People tacitly monitor each other; they make their activities sufficiently apperceptible for others; they take each others' past, present and prospective activities into account in planning and conducting their own work; they gesture, talk, write to each other, and so on. Accordingly, much of the research in CSCW has focused on providing enhanced means of communication, either in order to enable actors to cooperate more effectively and efficiently in spite of geographical distance, or in order to widen the repertoire of communication facilities.

However, in the complex work environments of modern industrial and administrative organizations, the problems of articulating distributed activities are at a different order of complexity. The everyday social and communication skills are far from sufficient in articulating the cooperative efforts of hundreds or thousands of actors engaged in myriads of complexly interdependent activities, perhaps concurrently, intermittently, or indefinitely.

> "As the scale and complexity of post-industrial societies and their organizations increase, the means of finding or creating order within them and the difficulty of doing so seems to multiply. […] Contemporary organizations in science, technology, and business have vast needs for coordination, scheduling, and order, which they often claim are unmet. […]
>
> This complexity presents a massive practical difficulty when it is embodied in an large-scale, multifunctional research and development or engineering design project. New product

> development in the automobile industry is probably one of the most complex systems for building civilian consumer products. It involves coordination among corporate planning, marketing, finance, body styling, product design engineering, tool and die design, and manufacturing (process) engineering. Among the product engineers alone, there are as many disparate specialties as there are systems in a car. Furthermore, some technical tasks, performed by specialists, must precede others in a relatively fixed sequence.
>
> In these automobile projects, time is treated first as a system of measurement. There is one master schedule, with checkpoints, approval dates, and milestones from the first 'concept approval' to completion of the first saleable vehicle. A normal span is four to six years of work. Within this schedule, there are multiple layers of more specific schedules, one for each group at each level of subdivision. Not only do these schedules chart the work of particular groups, but they also chart their relations with groups conducting parallel activities, and they connect beginnings and endings of groups that work in sequence." (Dubinskas, 1988, pp. 17-18)

In fact, design work does not have to be at exactly the overwhelming scale and complexity of automobile design to require the use of formal constructs as means of creating order.

Consider, for example, the case of the S4000 design project at Foss Electric, which shows this quite vividly:[12]

The S4000 project. Foss Electric is a Danish manufacturing company developing, producing, and marketing advanced equipment for analytical measurement of quality parameters of agricultural products. Equipment for measuring quality parameters of agricultural products is a highly specialized field and Foss has specialized in manufacturing equipment for measuring the compositional quality of milk (the fat content, the count of protein, lactose, somatic cells, bacteria, etc.), for measuring the composition and micro biological quality of food products, and for measuring grain quality. The measurement technologies involved are typically infrared, fluorescence microscopy, or bacteriological testing.

At the time of the field study, the company was engaged in a large design project called S4000. The objective of the this project was to build a new instrument for analytical testing of raw milk. The S4000 project was the first project aiming at building an integrated instrument that it would offer a range of functionalities that previously had been offered by a number of specialized instruments. In addition, as an innovation compared to previous models, the S4000 system would introduce measurements of new parameters in milk (e.g., urea and citric acid), and the measurement speed was to be radically improved. The instrument would consist of approximately 8,000 components grouped into a number of functional units, such as: cabinet, pipette unit, conveyer, flow-system, PC, and measurement unit. Finally, the S4000 was the first Foss instrument that incorporated an Intel-based 486 PC. The configuration and operation of the instrument was to be controlled via a Windows user interface. Eventually, version 1 of the software contained approximately 200,000 lines of source code.

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12 For a full description of Foss Electric and the S4000 Project, see (Borstrøm and Sørensen, 1994; Carstensen and Sørensen, 1994; Borstrøm et al., 1995).

More than 50 people were involved in the S4000 project, which lasted approximately 30 months (for version 1).

The designers were faced with quite a challenge:

(1) There are multitude interdependencies among the different subsystems: for example, between the various hardware components and the 200.000 lines of software, and between software control system and the mechanical and chemical processes in the flow and measurement system.

(2) The S4000 project introduced measurement of completely new parameters in raw milk for which new technologies had to be developed and mastered.

(3) The different subsystems were developed concurrently and the requirements to be satisfied by each subsystem would therefore change as other subsystems were developed.

(4) Production facilities are constantly changing as the use of existing machines is optimized and new machines and processes are introduced. Thus, the repertoire of manufacturing processes that the production function can offer to designers is constantly changing.

(5) Because of the technological diversity of the S4000, the project involved a number of specialities. The core personnel involved in the design included a number of designers from each of the areas of mechanical design, electronics design, software design, and chemistry. Added to this was a handful of draught-persons and several persons from organizational entities such as production, model shop, marketing, quality assurance, quality control, service, and top management.

The project was thus significantly more complex than the previous projects. As one of the software designer put it:

> "It has really been problematic that we did not have any guidelines and descriptions for how to produce and integrate our things. The individual designers are used to work on their own and have all the required information in their heads, and to organize the work as they want to [...] When we started, we were only a few software designers. And suddenly — problems. And ups, we were several software designers and external consultants involved".

In order to survive these challenges, the participants introduced a number of countermeasures for reducing the complexity the project:

First of all, a project-oriented matrix organization had been implemented. Projects are organizational units with the project manager serving as a "head of department" and all participants physically located in the same area. Participants could monitor events and maintain awareness of the state of affairs in the project at large, get assistance from colleagues when needed and so on.

Furthermore, to ensure that the project and the various sub-tasks were on track and that the interdependencies between units and processes were managed, a sequence of meetings was scheduled, some weekly and most twice per month. In the most intense phase of the project, 27 scheduled meetings, involving from 6 to 26 participants, were held. In addition, of course, to the scheduled meetings a lot of ad-hoc meetings were held.

However, the amount of detailed information that needed to be communicated, coordinated, negotiated, etc., required more formalized measures for the daily operation. Accordingly, a number procedures and artifacts were introduced to keep track of the integration or the state of affairs, to schedule relations and dependencies among involved actors, tasks, and resources. Some of the procedures and artifacts were invented for this project, some were redesigns of existing artifacts, and others were merely adopted.

The most dramatic measures were taken with respect to the software design process. The challenge faced by software design part of the project turned into a crisis — and the design goal was almost abandoned. To overcome the crisis, the software designers developed a complex of procedures and artifacts to ensure the monitoring and control of the integration of software components and modules. An important component in this complex, is the 'software platform' cycle (Borstrøm et al., 1995). At first, a 'software platform' was just a point in time at which all software designers would stop developing in order to integrate their bits and pieces; later on, artifacts and organizational procedures were added. For each platform period, one of the designers was appointed 'platform master' and was then responsible for collecting information on changes made to the software, and for ensuring that software is tested and corrected before it is released. Before the software is released as a 'platform' for further development, the project schedule is updated with revised plans and tasks for the next 3-6 weeks. The establishment of the software platform concept was considered absolutely necessary for the S4000 project. In addition, the software design team introduced other constructions such as the 'bug form' and the 'problems list' which support coordination among software developers with respect to the detection and correction of software errors (Carstensen, 1994).

The purpose of introducing the bug form mechanism and the whole apparatus of bug forms, 'binder', 'problems list', and procedures for classifying, correcting, and reporting on problems, was to ensure that problems were registered and that the allocation of responsibilities among designers was clear and visible to all designers, and to clearly stipulate how to report that a problem has been corrected. Furthermore, the problems list gave all designers evidence of the state of affairs in the software system as a whole and supported them in being aware of activities with respect to modules for which they were not responsible, but with which their own modules might have tight interactions.

The case of the bug form mechanisms is particularly valuable because we here witness the emergence of a mechanism of interaction in response to overwhelming problems encountered in coping with the complexities of articulating the cooperative design and testing of a large-scale software system. In the early phases of the software part of the S4000 project, the participants experienced an acute lack of overview and coordination. One participant characterized the problem this way:

> "With the number of developers involved, it is extremely important that all problems are registered, otherwise they just 'disappear' […] An important derived product then, is a list of prob-

lems reported fixed but not yet tested. Based on the lists and the problem descriptions the platform master can check and then report the problem corrected."

The participants experienced the hard way that it was practically impossible to handle a distributed testing and bug registration effort involving approximately twenty testers and designers without a mechanism of interaction that provided an overall functionality similar to the bug form mechanism. In order to prevent the project from failing, they therefore devised and implemented a mechanism of interaction.

Similarly, in the other strands of the S4000 project, other devices were introduced for the same purposes: (1) the Augmented Bill of Materials (ABOM) supporting integration between mechanical design, process planning, and production (Sørensen, 1994a); (2) The CEDAC board (Cause and Effect Diagram with the Addition of Cards) for integrating mechanical design and process planning (Sørensen, 1994b); and (3) the Product Classification Scheme supporting distributed classification and retrieval of CAD models (Sørensen, 1994c).

While daunting to the participants, the complexity of the S4000 project is not exceptional. Such complexities are an everyday occurrence in advanced manufacturing and in modern industrial, service, and administrative settings.

In such settings, characterized by a high degree of complexity of articulation work, the articulation of the distributed activities of cooperative work requires a certain mode of interaction in the form of artifactually embodied protocols that *stipulate and mediate* articulation work and thereby reduce the complexity of articulation work. We call such protocols 'mechanisms of interaction'.

In the following sections of this paper, we will expound this concept at length and in particular address some of the controversial aspects of it. However, in order for the reader to know where it all leads to, it may be useful to summarize the upshot of this discussion by stating the resulting formal definition of mechanisms of interaction:

A mechanism of interaction can be defined as a protocol, encompassing a set of explicit conventions and prescribed procedures and supported by a symbolic artifact with a standardized format, that stipulates and mediates the articulation of distributed activities so as to reduce the complexity of articulating distributed activities of large cooperative ensembles.

In other words, and less condensed, to serve the purpose of reducing the complexity of articulation work, a mechanism of interaction must have the following characteristics:

(1) a mechanism of interaction is essentially a *protocol* in the sense that it is a set of explicit procedures and conventions that stipulate the articulation of the distributed activities;

(2) the stipulations of the protocol are, in part at least, conveyed by a *symbolic artifact* and they are thus persistent in the sense that they are, in

principle, accessible independently of the particular moment or of the particular actor;

(3) at the same time, the symbolic artifact *mediates* the articulation of the distributed activities in the sense that any change to the state of execution of the protocol is conveyed to other actors in some form by means of changes to the state of the artifact;

(4) the symbolic artifact has a *standardized format* that reflects pertinent features of the protocol and thus provides affordances to and impose constraints on articulation work;

(5) the state of the protocol is *distinct* from the state of the field of work in the sense that changes to the state of the field of work are not automatically reflected in changes to the state of the execution of the protocol and, conversely, that changes to the state of the execution of the protocol are not automatically reflected in changes to the state of the field of work.

These defining characteristics will be discussed in the following sections.

4.1. Mechanisms of interaction and field of work

We will start by addressing the last, but fundamental, issue of the coupling between the field of work and the protocol.

In 1990, Bjarne Kaavé conducted a study of cooperative production control in a manufacturing company we can call Repro Equipment.[13] The company manufactures specialized optical appliances, and it covers about 50% of the world market for this category of equipment. The company currently produces about 6,000 units a year in 15 different models, each in 7 different variants.

The products manufactured by Repro Equipment are fairly large units, between 1 and 2 cubic meters each; a unit typically weighs about 300 kilograms. Simply put, the product consists of a cabinet housing a complex rigging of electrical equipment, electronic circuits, and optical instruments. The metal cabinet is produced in-house, typically by cutting, bending, and welding sheet metal. Most metal parts go through more than five processes before entering the assembly process.

Manufacturing involves multitudes of discrete parts and processes that are interdependent in multitude and enormously complex ways:

- each product consists of a many component parts, in some cases tens or hundreds of thousands of components;
- the production of each part may require a number of different processes in a specific sequence, and the production of different parts thus require different routings;

[13] This analysis is based on Bjarne Kaavé's findings as reported in his thesis (Kaavé, 1990) as well as in several joint analysis sessions with the present author.

- different processes may require specialized tools and skills, and different parts thus compete for the same workstations;
- many products are being manufactured simultaneously, and at any given time a large number of products and their components coexist at different stages of completion;
- in modern manufacturing with a large number of different models and variants to be manufactured in small volumes at short notice, different models and variants are being manufactured simultaneously.

Thus, in the words of Harrington (1984), manufacturing can be conceived as “an indivisible, monolithic activity, incredibly diverse and complex in its fine detail. The many parts are inextricably interdependent and interconnected.” Thus, as observed by Susman and Chase (1986), the various categories of workers — product designers, process planners, programmers, supervisors, operators, etc. — “will be highly interdependent with one another because of the need to exchange information to keep the factory operating.” Accordingly, for a manufacturing enterprise to be able to adapt diligently and dynamically to changing conditions, the entire enterprise must react “simultaneously and cooperatively” (Harrington, 1979, p. 35). Rapid and concerted adaptation of all the specialized functions of a diversified manufacturing operation, from Marketing to Shipping, to the vicissitudes of a volatile and complex environment is indeed the very essence of advanced manufacturing.

Kaavé’s study of Repro Equipment provides an interesting case of how a conventional production management system — an MRP II or Manufacturing Resource Planning system[14] — is appropriated and used cooperatively in controlling a manufacturing operation with characteristics far beyond the valid application domain of the system.

In conventional manufacturing, i.e., manufacturing of standardized products for fairly stable markets, the basic coordination mechanism of the diversified manufacturing operation — “the vital control center for the company’s manufacturing planning and control system” (Gunn, 1981) — is computer-generated a “master production schedule.” Based on forecasts and standard lead times for the various parts, the planning algorithm decomposes the material requirements and computes the schedules for the production of each part, sub-assembly, and assembly. The production control problem is thus, in principle, reduced to executing the plan and adhering strictly to schedules. That is, in so far as the underlying forecasts are accurate, coordination across functions and departments can be accomplished by plans and other organizational procedures. Direct cooperative interaction across functions only takes place to handle exceptional contingencies such as shortages or to expedite a high priority order.

At the heart of an MRP II system is a set of related models of essential aspects of the manufacturing operation. In order to understand the cooperative appropria-

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14 In casu, the COPICS system from IBM (IBM, 1972).

tion and management of the MRP II system, it is essential to understand the nature of underlying models — even if it is industrial engineering textbook stuff:

Bills of Materials: A bill of materials is an ordered list of every part that makes up the finished product (see Figure 10). The bill of material thus states that a particular assembly is made up of several parts that, in turn, can be components or sub-assemblies.

Item #	Description	Quantity
79111	Mounting Kit, Deluxe	1
47342	Mounting Kit, Basic	1
76504	Bracket, cast	1
64333	Bolt, 24 × 1”	2
30751	Nut, 24	2
22479	Washer, flat,	2
22842	Washer, lock,	2
16935	Clamp assembly	1
88327	U bolt	1
30750	Nut, self-lock, 24	2

Figure 10. Indented bill of material for part #79111 (Gunn, 1981, p. 15).

That is, the bill of materials is a hierarchical or tree structure denoting all parts and their relationships (see Figure 11). Based on the bill of materials it thus becomes a simple calculation to foresee which parts are required in which quantities in order to produce a certain number of a given product.

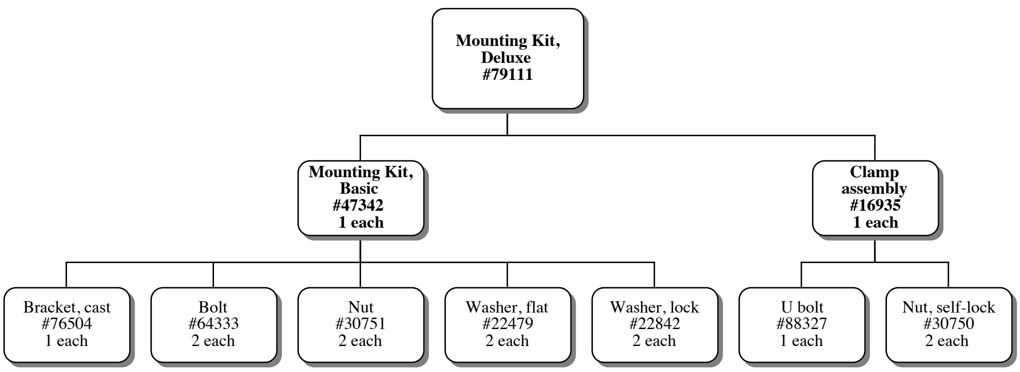

Figure 11. Product structure for part #79111 (Gunn, 1981, p. 15) showing the two-level hierarchy of parent parts (assemblies) and dependent parts (parts and sub-assemblies).

Routings or Process Sheets: The process sheet specifies and lists, in sequence, each manufacturing operation a part or sub-assembly must go through to be manufactured (see Figure 12). For each operation the average processing time is listed, based on a statistical study “performed over some production period, or from standard time study figures, or just the foremen’s best estimate” (Gunn, 1981, p. 25). However, the production cycle time does not indicate the number of labor hours required to produce the part. The number of labor hours required depends on the number of people required at each operation. Thus, the process sheets will often specify the average production cycle time as well as the average labor hours required.

Dept.	Description	Operation	Production cycle time	Labor hours required	Total labor hours required
100	Machining				
		Machine center 100		6	
		Work station 140		4	
		Machine center 150		2	
		Subtotal, dept. 100	2		12
200	Assembly				
		Work station 210		4	
		Work station 270		2	
		Subtotal, dept. 200	3		6
300	Crating				
		Work station 350		2	
		Subtotal, dept. 300	1		2
Total			6		20 hours

Figure 12. A routing or bill of labor for part #1050 (Gunn, 1981, p. 26).

Labor hours and calendar time is not necessarily the same, of course. That is, the time from a part enters a particular work station and until it arrives at the next work station is normally larger than the production cycle time as a direct function of labor hours required. In traditional manufacturing, a part was normally only processed 5% of time it spends underway from start to finish, and queue time alone could take 80-90% of the entire production cycle. In fact, the production cycle for each part involves several operational stages: apart from the time required for processing which involves set-up time and run time (e.g. the various machining or assembly operations), parts spend time in queues before and after processing and while being moved between work centers (see Figure 13).

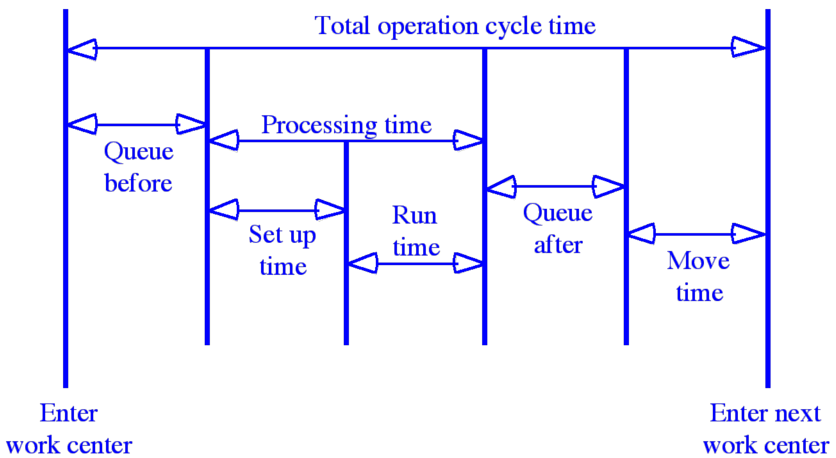

Figure 13. Elements of total operation cycle time (Gunn, 1981, p. 26).

The time required to produce different parts varies, of course. Thus, in order to produce a particular end item at a particular due date, the production of the different component parts must be initialized at different points in time. By coupling the model of the structure of parts and assemblies and the models of the routing and process characteristics of each part and assembly, it is then possible to calculate the due date of the various components parts based on the due date of the orders of the end or parent item.

Since the operation cycle times for each part are specified in the routing sheet alongside the labor hours required, the total work time required for a batch of a particular part can be calculated as the queue time plus setup time plus the lot size multiplied by the run time per part. Thus, it is also possible to calculate the capacity requirements at each point in the production of a given end item.

The master production schedule is a time-phased plan identifying the aggregate capacity requirements at a company level. It is thus "the vital control center for the company's manufacturing planning and control system" (Gunn, 1981, p. 66). In conventional manufacturing, where production — to a large extent — has been planned on the basis of forecasts of expected sales, the master production schedule is computed on the basis of the sales forecasts for each product or family of products (plus, of course, actual sales demands) coupled with the models of product structure and the models of the routing and process characteristics of each part and assembly. Given a master production schedule based on reliable forecasts, the production control function is — for all practical purposes — reduced to ensuring that the detailed plan is executed properly.

A major problem with MRP II-based production control, however, is that is involves a significant element of guesswork:

> "a weakness of MRP is that there is some guesswork involved. You need to guess what customer demand will be in order to prepare the schedule, and you need to guess how long it will take your production department to make the needed parts. The system allows corrections to be made daily (called shop-floor control). Nevertheless, bad guesses result in excess inventories of some parts" (Schonberger, 1982, pp. 220 f.).

That is, MRP II-based production control is only feasible under certain conditions. The most important precondition is that the enterprise manufactures a limited number of products for a predictable market, that is, under conditions where deviations of sales from expected demand can be parried by inventories of final products.

These preconditions ceased to exist in Repro Equipment as a consequence of the strategic shift in 1974. Nevertheless, the MRP II-based production planning and control system is still used intensively. Why?

The COPICS system at Repro Equipment is used to generate production orders. In addition, it is used to record production orders that have been accomplished and to ensure that operators are paid when a production order has been carried out.[15]

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15 The blue collar workers at Repro Equipment are paid on the basis of a negotiated piece rate tariff.

The system still generates production orders based on projected demand (a simple monthly average) but actual customer orders are no longer assumed to match projected demand. To the contrary, the totality of COPICS-generated production orders are treated as a hypothetical plan that ensures that appropriate material resources in the form of parts and sub-assemblies can be made available in order to meet actual demand as derived from the order book and propagated down the line.

Each decision maker then compares the set of COPICS-generated production orders with the actual demand. If customer orders fall within what has been planned by COPICS on the basis of average demand, the operators simply stick to the master schedule and executes the COPICS-generated production orders.

However, if customer orders are beyond the plan, operators override the plan and 'grab' a production order and redirect and reschedule it. Thus, when the actual customer order situation is not matched by the resource envelope established by COPICS, the network of local decision makers have to find out if and how the desired production can be made. This may result in a change in the sequence in which orders are produced or in the generation of new production orders and thereby in the creation of a different resource envelope.

In addition to the absence of reliable forecasts and the large number of product variants, there are other reasons for overriding the master schedule generated by COPICS.

First, some parts — the components of the cabinet — are extremely bulky. "They take up space like hell". These parts are not produced for buffer stocks. Their production is therefore always controlled manually. However, the equipment produced by Repro Equipment only comes in three sizes, which means that the fluctuations in demand for the different models sizes are fairly small and cabinet parts can be produced in a flow-like manner.

Second, if suddenly some parts are missing — a fault may have occurred during painting — then that production order is 'carried by hand' all the way through the factory, that is, its production is controlled manually.

And third, changing from one color to another in the paint cabin requires that the paint cabin is thoroughly cleaned. So, when an order for, say, white products have to be made (only some 10 % of all products are painted white), it is important to make sure that all parts for that order are ready for being painted at the same time. This creates a wave throughout the plant: "We are painting white Friday — we need all parts to be painted white by then."

Anyway, whatever the reason for overriding the master schedule, the COPICS system is invaluable as a support to the operators in this cooperative manual control of production. In the words of Kaavé in one of the analysis sessions:

> "When he takes an order that only were to be carried out two weeks later, that resource withdrawal is recorded in the complex continuously controlled by COPICS. During the night, COPICS then tries to correct the accident — as it sees it — that suddenly 25 more right legs have been withdrawn than it had expected. It then computes — based on the MRP model —

how to produce these parts anyway so that the plan is maintained. So, even if the system ought to break down if you do things like that, you are not severely punished.

The MRP model in COPICS saves the planner every time he does a stunt like that. Because it tries to correct — it tries to maintain a kind of balance. Every time they steal something in one end it tries to resurrect balance.

They exploit the fact that the MRP model generates new production orders when you withdraw parts. If you use some parts, the model enters and plan to produce some new ones. It does not know that the demand is fluctuating. It assumes that you need the same number every month.

It pours water into the jar again. The jar is always refilled." (Kaavé, 1992)

In other words, what enables and motivates the operators at Repro Equipment to use the MRP II system in a manufacturing operation that is basically order driven — as opposed to inventory driven — is the underlying models of pertinent interdependencies of the manufacturing operation at Repro Equipment: the vast array of Bills of Materials of all assemblies and sub-assemblies; the average set-up times and processing times of all manufactured parts and assemblies; the average lead time of purchased items etc. By incorporating such a set of related models of essential interdependencies, the MRP II system reduces the immense complexity of scheduling the production of a vast number of parts in a distributed setting by trying to maintain the fictitious master schedule based on projected average demand. It thus provides an essential service to an order-driven manufacturing operation.

However, in order for the MRP II system to be used in the way described above some important changes have been made to the design of the production control system:

First, because COPICS-generated production orders are not treated as operational orders but rather as hypothetical orders, the production orders printed by COPICS are placed in "the box", that is, an archive of pending production orders. The archive is under the jurisdiction of the production planner. When pending orders are to be executed, they are retrieved and finally placed in "the rack" where they are publicly visible and accessible. Operators are now allowed and expected to pick them up and produce the parts.

In other words, the *direct coupling* between (a) the state of the field of work for the cooperative production control activities (i.e., the manufacturing operations in its totality) and (b) the representation of the field of work in the COPICS system has been severed. The coupling is now merely hypothetical, pending human intervention (approval, modification, cancellation). Control of the production process is thus squarely in the hands of the cooperative ensemble.

Second, the COPICS system has itself been modified accordingly. It now has three check-boxes providing information about the status of each particular production order:

- ❏ Has been printed
- ❏ In the rack

❑ Taken by engineer

The first check-box is marked automatically by COPICS when the production order is printed, whereas the production planner marks the second box when the order is retrieved from the archive box and placed in the rack for execution. The latter box is marked by the foreman when the order is taken by an engineer.[16]

The MRP II system thus provides a means of perceiving the state of affairs in various parts of the plant.

The foreman in Assembly may for instance notice, while walking around, that 'his' buffer stock of some type of parts is low. He may think, "Next week we'll probably be out of these fuse sockets for Asia." He will then turn to COPICS to see if the system has planned an order that can be fulfilled in time for him to get them. He simply looks up in the system: "Does it look like I'll be getting a problem next week?" He can see that quite precisely. He can for instance see whether the sub-parts of that particular part are being machined or not or whether the production order has been placed on the board for the engineers to take it.

This way of cooperative production control points out new demands to production management systems, where the existing planning system must be supplemented with facilities that support local decision makers in their planning and evaluation tasks. The role of the planning system is simply changing as local actors are deciding which orders should be put into production, and new systems must enable local actors to generate orders when the set of expected production orders is not creating the needed resource envelope.

That is, in the company we have called Repro Equipment, the MRP II-based production planning system is used in a production control mode based on actual customer order as opposed to a mode of production control based on reliable forecasts of demand. The MRP II system is thus used in a context far beyond its valid application domain.

Nevertheless, the MRP II-based system is used (a) to coordinate the mass of activities that does not need to be handled manually; (b) to coordinate the execution of customer orders well within the projected average demand; (c) to compute and counteract potential adverse effects of manually overriding the hypothetical master schedule; and (d) to provide all those involved in the control of production at large with a representation of the state of the field of work.

The MRP II-based system is able to provide this support because it incorporates a set of interrelated models of pertinent interactions and interdependencies in the field of work. However, the COPICS system has been redesigned so as to support its use as a mechanism of interaction: By introducing a manually control-

16 The engineers are allowed to chose which order to pick. This allows them, to a certain extent, to avoid changing the set-up at their individual workstations for each order and thus enables them to make a handsome wage. Their choice of job is to be approved by the foreman in order to ensure that no engineer consistently skips rush orders for the sake of maximizing his income.

led 'buffer' archive of printed production orders between COPICS and the production process and by recording and displaying the state of each COPICS-generated production order, *the direct coupling between (a) the state of the field of work for the cooperative production control activities (i.e., the manufacturing operations in its totality) and (b) the representation of the field of work in the COPICS system has been severed*. The coupling is merely hypothetical, pending human intervention.

4.2. The problematic nature of stipulations of articulation work

While the notion of protocols stipulating the articulation of cooperative work is crucial to the concept of mechanisms of interaction, it is also contested. In a large body of sociological literature, the notion of pre-defined organizational constructs (formal structures, procedures, methods, plans) as determinants of action has been subjected to critical examination. Study after study has demonstrated, unambiguously and beyond any doubt, that the status of these formal organizational constructions in the actual course of work is problematic in the sense that these constructions are impoverished idealizations when taken as representations of actually unfolding activities. In the words of Philip Selznick's classic summary of this line of sociological investigation:

> "The formal administrative design can never adequately or fully reflect the concrete organization to which it refers, for the obvious reasons that no abstract plan or pattern can — or may, if it is to be useful — exhaustively describe an empirical totality. At the same time, that which is not included in the abstract design (as reflected, for example, in a staff-and-line organization chart) is vitally relevant to the maintenance and development of the formal system itself." (Selznick, 1948, p. 25)

Later, in the context of examining the assumptions of the nature of office procedures underlying 'office automation,' Lucy Suchman and Eleanor Wynn raise the same question: "how adequately do these accounts describe how office work gets done?" and make a quite similar point:

> "The problems involved in accomplishing office tasks, while central to work practices, are ignored in procedural formulations of how the work gets done. The point of this observation is not to critique procedural formulations, but to indicate *another domain of the work*, in which those formulations are brought to bear on the practical contingencies of actual tasks." (Suchman and Wynn, 1984, p. 139)

This conception of the status of 'formal constructions' has been highly influential in that it, as observed by Egon Bittner in a now classic paper, has "furnished the necessary theoretical argument for an entire field of sociological investigations by directing attention to a sphere of adaptive and cooperative manipulations, and to the tensions typically found in it." (Bittner, 1965, p. 240)

Now, how do sociologists go about distinguishing the facts of formal organization from the facts of informal organization? The methodological rule for making this distinction can, in Bittner's words, be stated this way:

> "In certain presumptively identified fields of action, the observed stable pattern of conduct and relations can be accounted for by invoking some *programmatic constructions* that define them prospectively. Insofar as the observed stable patterns match the dispositions contained in the program they are instances of formal organizational structure. Whereas, if it can be shown that the program did not provide for the occurrence of some other observed patterns which seem to have grown spontaneously, these latter belong to the domain of the informal structures." (Bittner, 1965, p. 240)

The problem for Bittner — and for us — is: what is the status of these formal organizational constructions? The problem with the received tradition of critical studies of formal organizational constructions, however, is the almost ceremonial status it implicitly ascribes to these formal constructions and the ensuing dichotomy of the 'formal' and the 'informal', the notional and the corporeal. The argument implies that members of the organizational settings in question are somehow supposed to take formal constructions literally — as if constructions such as procedural formulations are supposed to be exhaustive specifications of how the work gets done.

It is important to note, in the context of this discussion, that Wynn and Suchman in their analysis were motivated by other issues than the ones addressed here. When for instance Wynn states that "the world of human activities, with all its complexity, cannot necessarily be expected to run the schedule idealized in procedure" (Wynn, 1991, p. 62), she is not implying that members of the office she has studied did believe or were supposed to believe the opposite, but is presumably rather arguing against views held by outsiders to the domain (managerial ideologists, designers of 'office automation' systems, office equipment vendors, etc.). And in so far as Wynn and Suchman demonstrate that such crude preconceptions by outsiders to the office domain are unfounded, their observations and findings are, of course, quite pertinent.

However, for our purpose we need to be far more specific as to the role of formal organizational constructions such as prescribed procedures in articulating cooperative work. In addressing this problem, in relation to Selznick's conception of formal structures as normative idealizations, Bittner makes some very cogent observations:

> "Together with Weber, Selznick assumes that the formal structures represent an ideally possible, but practically unattainable state of affairs. While Weber outlined the contents of the normative idealization in general terms, Selznick pointed out that the normative idealization, to be an effective source of restraint, must be constantly adapted to the impact of functional imperatives of social systems. Thus he furnished the necessary theoretical argument for an entire field of sociological investigations by directing attention to a sphere of adaptive and cooperative manipulations, and to the tensions typically found in it.
>
> Despite the gain, the argument retains a certain theoretical short circuit. While Selznick quite clearly assigns the formal schemes to the domain of sociological data, he does not explore the full range of consequences out of this decision. By retaining Weber's conception of them as normative idealizations, *Selznick avoids having to consider what the constructions of rational conduct mean to, and how they are used by, persons who have to live with them from day to day. It could be, however, that the rational schemes appear as unrealistic normative ideali-*

> *zations only when one considers them literally, i.e., without considering some tacit background assumptions that bureaucrats take for granted*." (Bittner, 1965, p. 242 - emphasis added)

Bittner's methodological recommendation is quite pertinent to the issue of analyzing and designing mechanisms of interaction. In order to be able to contribute constructively to the design of mechanisms of interaction, we need to understand not only "the tacit background assumptions" that members take for granted and without which any formal construction would be a flatulent and rhetorical statement but also "what the constructions of rational conduct mean to, and how they are used by, persons who have to live with them from day to day".

4.2.1. Critiquing formal constructions in cooperative work

Consider, for example, Louis Bucciarelli's fine study of design work.

The solar power panel project. Bucciarelli's study is based on several years of ethnographic investigation of design at an engineering firm engaged in making photovoltaic modules for the production of electrical power from sun light (Bucciarelli, 1988). In his analysis of the findings, Bucciarelli questions the status of the organizational constructs and artifacts used in that particular setting:

> "The milestone chart […] can be viewed as a snapshot of a month in the life of a participant in design, a picture of how his or her time is to be 'spent' over the next one or several months. […] The chart suggests that there exists clear and distinct beginnings and ends to design tasks. What can be surer than a 'deadline'?" (Bucciarelli, 1988, p. 98)

In general, Bucciarelli argues, charts such as the milestone chart and the critical path chart "suggest that tasks are all of a finite duration and bounded by well-defined starting dates and deadlines" (p. 104) but to mark "the origin of a design of a particular product is impossible" (p. 105).

The milestone chart, in Bucciarelli's analysis, offers an "illusion of definiteness":

> "While it suggests the continuous chinking away of a finite number of days to come, from the perspective of the individual whose milestone chart it is, the exercise of its construction has an element of fantasy about it, asking for too high a degree of precision in pacing future, uncertain events.
>
> To account for one's future in the terms of the chart engenders an uneasiness, a sense that its format is too confining and disallows any adequate explanation of what it will take to get the job done." (Bucciarelli, 1988, p. 107)

The obvious question that comes to mind, if of course, why members of design teams would use such decidedly "misleading" constructs (p.106). Bucciarelli's answer is that the utility of these construct is in their construction:

> "The milestone chart and the other diagrams and instruments are abstractions whose intent is to facilitate agreement on the way participants as well as subsystems and elements must relate and flow through time for design to succeed. They are like maps — subway maps, contour maps, street maps — all covering the same terrain but focused differently. But although they appear as plans of how hours and resources are to be neatly spent in the future, they are rarely referred to once the meeting is over. Their construction, their social construction, is what is significant to the design process. After the meeting, the chart remains in the desk drawer or on

the bulletin board for reference, but it is usually superfluous for day-to-day travels. Its importance lies in its creation." (Bucciarelli, 1988, p. 114)

The core of Bucciarelli's interpretation is the contention that the chart "suggests" that there exists clear and distinct beginnings and ends to design tasks and that it thereby offers an "illusion of definiteness". However, this proposition is methodologically dubious: To whom does the chart make such illusionary suggestions? There is, of course, no reason to doubt that the milestone chart remains in the desk drawer after the meeting or on the bulletin board for reference and that it is usually superfluous for day-to-day activities. The point we want to raise here is the general validity of this observation. This issues has been raised by Dubinskas in an interesting comment to Bucciarelli's study (Dubinskas, 1988). Comparing Bucciarelli's findings to his own observations from the automobile industry (cited above), Dubinskas notes that the temporal and design flexibility observed by Bucciarelli in the solar energy panel project is not to be expected in automobile design. In the solar energy panel project,

"The number of people and components was lower, the range of expertise was much narrower in scope, and the design process took place in a largely face-to-face environment. Schedule building was intimately tied to the progressive emergence of the artifact — the panel — and the project direction was perhaps less clearly defined (or constrained) technically than new car development is. One result was that schedule formation became a regularized forum for negotiations about the order of work and the character of the artifact." (Dubinskas, 1988, p. 18)

Dubinskas' point ties in with the point we have made in previous sections, that the articulation of cooperative work may pose different degrees and kinds of complexity to the cooperative ensemble and that mechanisms of interaction arise to handle this complexity. Due to the special conditions highlighted by Dubinskas, the participants of the solar energy panel project may have been able to articulate their various activities without, for instance, relying on the stipulations of the milestone chart which, in stead, "remains in the desk drawer or on the bulletin board for reference".

The case of the S4000 project illustrates this eloquently. The designers involved in this project had previously been involved in design projects which could be handled in very much the same way as the solar panel project described by Bucciarelli. However, the participants of the S4000 experienced that this way or coordinating design work was no longer possible. They had to invent, or reinvent, various formal organizational constructions and a whole suite of supporting artifacts to get the job done.

A few studies of the use of office procedures that have questioned and analyzed the status of office procedures from a perspective which has been highly influential in CSCW deserve to be reexamined carefully for their evidence on the status of standard operating procedures in administrative work.

The accounting office. Suchman's study of "office procedures as practical action" (1983) explicitly takes issue with the conception of office work underlying the Office Automation movement and specifically addresses the fundamental problem of the status of procedural specification:

> "A central concern of current office research and system design is the representation, specification, and automation of office procedures. That concern is based on the view that office work is essentially procedural in nature, involving the execution by office workers of a prescribed sequence of steps. [...] Affiliated with the procedural paradigm are certain persistent troubles, however, that appear in management and computer science alike. For organization theorists these troubles are located in the elusive domain of 'informal' or 'unstructured' activities. [...] Rather than attempting to do away with the incompleteness of procedural specifications (an endless task), the research begun here views the problematic nature of procedural implementation as an irremediable fact. In this view, the uncertain relationship of procedural specifications to the work required to 'carry them out' is a special case of the general relationship of any normative rules to the actual occasions of their use. The topic for study is the process of finding the 'definite meaning' of office procedures as a constituent feature of the work of getting them done. The work of finding the meaning of organizational plans in actual cases is referred to as *practical action*. The structures of the office, accordingly, are located in the organization of practical action, rather than in procedural specifications *per se*." (Suchman, 1983, p. 321)

The accounting office studied by Suchman is responsible for the orderly payment of money due to outside organizations supplying goods and services to the organizational units in its charge. Orderly payment is documented through the office's record-keeping, and accuracy is monitored by the auditing of invoices against records of requisition and receipt.

According to Suchman (p. 323), the following sequence "occurs" in the "smooth flow" of paper on a given purchase:

(1) The facility's procurement office issues a purchase order (P.O.). Three copies are distributed: one each to the supplier, the shipping/receiving department of the facility, and the Accounting Office.

(2) The Accounting Office copy is filed in a temporary file.

(3) As the items ordered arrive at the receiving department they are marked off on the receiving department's copy of the purchase order (the receiver), a copy of which is in turn sent to Accounting.

(4) Invoices issued by the vendor arrive in the Accounting Office via the U.S. mail. On arrival they are matched with the waiting purchase order and receiver.

(5) With the purchase order, receiver, and invoice in hand, the audit of price, quantity, sales tax, account numbers, part numbers, and so forth, can be done.

(6) On completion of the audit, with no discrepancies encountered, the work necessary to a generation of payment begins.

(7) When the payment is issued, the invoice, purchase order, and receiver are attached behind a copy of the check and filed away in the paid file.

Suchman's description of the case does not indicate whether this sequence is explicitly stipulated in a written text. In most accounting offices, however, this would be the case.

In her analysis, Suchman highlights one specific routine complication. Items on a given purchase order may be received and billed in separate installments over an extended period of time. Again, if all goes smoothly, the items marked off on the receiving report from Shipping/Receiving correspond to those on the invoice from the vendor. The purchase order, receiver, and invoice are matched and audited. The payment for the items received is recorded by margin notes on the purchase order, which is then returned to the temporary file to wait for the next shipment and billing. Only after all bills have been received and paid is the completed purchase order filed permanently in the paid file.

According to Suchman, the data on this case are constituted principally by a lengthy session of collaborative work between the accounts payable auditing clerk, and the accounting supervisor. The auditing clerk's work on the case begins with the arrival of a past due invoice in the mail. As a claim of money owed by the unit at hand, the arrival of any invoice from an outside supplier initiates action. As a claim of payment overdue, a past due invoice is a formalized notice of trouble.

If a past due invoice were taken at face value, payment could simply be issued without delay. But before making payment the Accounting Office must establish the legitimacy of the vendor's claim. A review of past actions taken on the order, as recorded in Accounting Office files, is the primary resource for that task.

In the case presented and analyzed by Suchman, however, the record of what happened is incomplete: The original purchase order is missing. A completed receiving document is found with are eight items listed on it, all of which have been marked as received. But the two invoices found in the paid file show only two items (3 and 8) as paid; there is no invoice or record of payment for the other items (1, 2, 4, 5, or 6 and 7), yet the vendor reports that the transaction will be completed with payment of the past due invoice for items 6 and 7. Two packing slips and a receiving document show items 1, 2, 4, and 5 received with item 8, but the invoice to which they are all attached shows item 8 only. According to the records of the Accounting Office it appears, then, that there are in fact *six* items whose payments are due (1, 2, 4, 5, *and* 6 and 7). Nonetheless, the vendor reports that the past due invoice (for items 6 and 7 only) is the final payment, and the receiving department reports all the items received.

The case then shows how the two actors, the accounting clerk and the auditing clerk, step by step solves the 'mystery': Of the invoice for item 8, only page two is on file; page one is missing. It thus transpires that items 1, 2, 4, and 5 were invoiced with item 8 and had already been paid. The missing invoice page also works to explain why there are two packing slips with the invoice for item 8.

Suchman's interpretation of the case is debatable. Consider this:

"Standard procedure is constituted by the generation of orderly records. This does not necessarily mean, however, that orderly records are the result, or outcome, of some prescribed sequence of steps. Workers in the Accounting Office are concerned that (1) money due should be paid, and (2) that the record should make available both the warrant for payment and the orderly process by which it was made. In this case, once the legitimate history of the past due invoice is established, payment is made by acting as though the record were complete and then filling in the documentation where necessary. The practice of completing a record or pieces of it after the fact of actions taken is central to the work of record-keeping." (p. 326).

True, the case shows convincingly that orderly records are not necessarily the result of some prescribed sequence of steps and that may involve the practice of completing a record or pieces of it after the fact of actions taken. But since the case analyzed by Suchman is a case of *recovery from error* in an administrative agency, *it provides little, if any, insight into how standard procedures, defined as pre-defined written stipulations, are applied in routine daily work*.[17]

It is therefore difficult, if not impossible, to conclude that accounting work (for instance, orderly payment of money due to outside organizations supplying goods and services) does not — in normal circumstances where records are complete — result from working according to some prescribed sequence of steps:

> "Standard procedures are formulated in the interest of what things should come to, and not necessarily how they should arrive there. It is the assembly of orderly records out of the practical contingencies of actual cases that produces evidence of action in accordance with routine procedure. This is not to say that workers 'fake' the appearance of orderliness in the records. Rather, it is the orderliness that they construct in the record that constitutes accountability to the office procedures." (Suchman, 1983, p. 327)

In so far as the case at hand is concerned, Suchman has documented quite convincingly that, in this situation, it is the assembly of orderly records out of the practical contingencies of the actual case and not according to a prescribed sequence of steps that produced evidence of action in accordance with routine procedure. However, in her study there is no empirical basis for the quite general claim: "Standard procedures are formulated in the interest of what things should come to, and not necessarily how they should arrive there. It is the assembly of orderly records out of the practical contingencies of actual cases that produces evidence of action in accordance with routine procedure." The study presents an analysis of a recovery from breakdown. Consequently, it does not attempt to demonstrate that prescribed procedures do not — in some form and to some extent — determine the handling of routine cases; it does not even attempt to give an analysis of how prescribed procedures are used in routine cases. Nonetheless, the reader is left with the impression that no prescribed procedure exists or, if a prescribed procedure does exist, that is has no implications for the actual conduct of work; the routine procedure is claimed merely to "occur" "in" the "smooth flow" of paper on a given purchase (p. 323), as a result of "the assembly of orderly records out of the practical contingencies of actual cases".

Accordingly, Suchman's general conclusion is not supported by the evidence of the case:

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17 Standard operating procedures are, of course, instrumental in defining what constitutes an 'error' in a particular setting and how to detect whether or not there is an error and what kind of error it might be. The point we want to make here, however, is that a procedure may work quite differently under routine conditions and under breakdowns.

> "The operational significance of a given procedure or policy is not self-evident, but is determined by workers with respect to the particulars of the case in hand. Their determinations are made through inquiries for which both the social and material make-up of the office setting serve as central resources. This view recommends an understanding of office work that attends to the judgmental practices embedded in the accomplishment of procedural tasks." (Suchman, 1983, p. 327).

Suchman does not provide evidence to show *how* actors, in routine situations, deal with procedures, nor does she demonstrate that the operational significance of a given procedure is not 'self-evident' *to competent members*. More than that, the conclusion raises some fundamental issues: Is the operational significance of a given procedure really never self-evident to competent members? We will revert to this question below.

Anyway, precisely because it is a case of recovery from error, the case also provides a graphic impression of the massive heuristic use of standard procedures even in a seemingly abnormal situation. The two actors are able to solve the abnormal problem because of their "knowledge of the accounts payable procedure" (p. 322). Standard procedures have a heuristic function in the sense that they "are formulated in the interest of what things should come to, and not necessarily how they should arrive there" (p. 326). The case thus gives us an insight into the crucial role of prescribed procedures even in the handling of contingencies. The case shows that prescribed procedures convey important heuristic information for the handling of errors as well as routine tasks.

The supply center. The study by Eleanor Wynn of office communications (Wynn, 1979; Wynn, 1991) poses similar problems with respect to the way it is being conceptualized. Wynn investigated conversational interactions in a supply center in the Western United States that handled telephone orders for office supplies on a regional basis. The staff consisted of ten telephone sales people, three customer service representatives, two inventory people, two billing clerks, and a few other. (Wynn, 1979). The objective of Wynn's study is to "describe some of the commonly occurring 'hidden' or implicit activities that constitute the operational background of office work" (p. 1). The study is motivated by her indignation with managerial assumptions of the intellectual competence of the clerical work force according to which office work requires no particular competence and intellectual skill (pp. 30-32). Consequently, the study is focused on demonstrating how social competences are involved in office conversations.

The re-analysis of the case (Wynn, 1991), however, revolves around a distinction between 'procedure' and 'practice': "real performance in the job is by no means merely a matter of procedure" (p. 46). However, the pieces of evidence mobilized for the purpose of the re-analysis are not particularly appropriate for precisely this set of issues; they are all situations of recovery from error (pp. 57 f., 59 f.) or of recovering from a change of procedure (pp. 61 f.).

Wynn concludes her re-analysis by stating that "the world of human activities, with all its complexity, cannot necessarily be expected to run the schedule idealized in procedure. Yet the formal requirements must somehow be met" and adds that "the elicitation of a description of procedure — of how a manager idealizes the organization's functions — has a good chance of missing key elements of the real way things are done" (Wynn, 1991, p. 62). This is an important observation but, again, the study does not provide an analysis of what actors do with procedures, how they interpret and apply them, under the conditions for which they were devised. Procedures are simply conceived of as managerial idealizations and contrasted with the practices of handling non-routine situations which, presumably, are beyond the bounds of the procedures.[18]

While the case studies discussed above have contributed substantially to our understanding of the articulation of cooperative activities in different settings and have been highly influential in dissipating the simplistic notion of the 'office automation' movement, they are, however, problematic in that the evidence of the cases does not seem to warrant the general conclusions claimed by the authors: in conceptualizing the status of formal organizational constructions such as procedures, the authors do not take into account the fact that the situations studied are beyond the 'jurisdiction' of these formal constructions, that is, beyond he operational conditions for which they have been designed.

The point of this argument is that, contrary to what is claimed by the general conclusions of these studies, *the use of procedures under everyday routine conditions* for which such procedures are designed, has not been investigated and that the studies therefore, unwarranted, diminish the role of stipulations in cooperative work.

In fact, this conception of formal constructions underrate their role considerably, in some cases dramatically. As pointed out by Bittner, this is an empirical question. In stead of merely observing in case study after case study that procedures are impoverished abstractions when confronted with the multifarious nature of practical action, it is necessary to investigate precisely *how* protocols stipulate the articulation of cooperative work, *how* they are interpreted and used, designed and adapted by competent actors "who have to live with them from day to day".

4.2.2. Towards a theory of the status of protocols in cooperative work

In her seminal work on *Plans and Situated Action*, Suchman critiques the highly idealistic conception of the relation between plan and action underlying the cognitive sciences[19] and argues forcefully for a paradigmatic shift:

> "Rather than build a theory of action out of a theory of plans, the aim is to investigate how people produce and find evidence for plans in the course of situated action. More generally, rat-

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18 It should be noted, however, that Wynn's original study is far more careful in its generalizations (cf. Wynn, 1979, pp. 27-29) and that it in a very differentiated manner distinguishes the 'routine' character of work of the supply order entry clerks with the 'non-routine' character of the work of the customer service representatives (pp. 42-50).

19 In the cognitive science conception of the relation between plan and action, Suchman points out, "the plan as stipulated becomes substitutable for the action, insofar as the action is viewed as derivative from the plan. And once this substitution is done, the theory is self-sustaining: the problem of action is assumed to be solved by the planning model, and the task that remains is the model's refinement." (Suchman, 1987, p. 37).

her than subsume the details of action under the study of plans, plans are subsumed by the larger problem of situated action." (Suchman, 1987, p. 50)

Expounding this materialistic conception of plan and action, Suchman posits that

> "plans are resources for situated action, but do not in any strong sense determine its course. While plans presuppose the embodied practices and changing circumstances of situated action, the efficiency of plans as representations comes precisely from the fact that they do not represent those practices and circumstances in all of their concrete detail" (Suchman, 1987, p. 52).

The thesis that "plans are resources for situated action" is of fundamental importance to CSCW systems design and has served as a guiding principle in the development of the concept of mechanisms of interaction. But it also leaves a number of disconcerting questions unanswered: What is it that makes plans, schedules, procedures, classification schemes, etc. useful in the first place? What makes them "resources for situated action"? Furthermore, is it merely the fact that plans are underspecified in comparison with the rich multiplicity of actual action that makes them "resources"? Is that really all there is to it?[20] What, then, makes one procedure or form or schedule more useful than another for a certain purpose in a specific setting?

Suchman expands on the thesis in further detail in the concluding remarks to the book:

> "The foundation of actions […] is not plans, but local interactions with our environment, more or less informed by reference to abstract representations of situations and of actions, and more or less available to representation themselves. The function of abstract representations is not to serve as specifications for the local interactions, but rather to orient or position us in a way that will allow us, through local interactions, to exploit some contingencies of our environment, and to avoid others." (Suchman, 1987, p. 188)

Accordingly,

> "when we look at actual studies of situated action, it seems that situated action turns on local interactions between the actor and contingencies that, while they are made accountable to a plan, remain essentially outside of the plan's scope. Just as it would seem absurd to claim that a map in some strong sense controlled the traveler's movements through the world, it is wrong to imagine plans as controlling actions. On the other hand, the question of how a map is produced for specific purposes, how in any actual instance it is interpreted *vis-à-vis* the world, and how its use is a resource for traversing the world, is a reasonable and productive one." (Suchman, 1987, pp. 188 f.)

Unfortunately, Suchman's analysis of the relationship between 'plan' and 'action' is characterized by a remarkably abstract manner of reasoning which can be attributed to the underlying critique of the extremely abstract presumptions of cognitivism that drives it. Thus the term 'plan' is used both to denote very real formal organizational constructs (as embodied in standard operating procedures, checklists, charts, forms, schedules, and so forth) as well as the putative cognitive

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20 Is it indeed "*precisely* […] the fact that they *do not* represent those practices and circumstances in all of their concrete detail" that makes plans efficient and effective? Does that means that the less specific the better? Suchman probably does not intend to imply that.

constructs suggested by cognitive scientists to account for the orderly accomplishment of a task by skilled actors (e.g., Micronesian navigators).

Oddly, the examples of plans as "resources for situated action" given by Suchman in the course of her analysis are restricted to purely mental constructs, namely plans one may devise prior to running rapids in a canoe, and the craft strategies that account for the navigational skills of Micronesian navigators. What is peculiar about these examples is that they are a far cry from the realities of normal cooperative work settings in contemporary industrial society characterized by massive use of organizational protocols or scripts, often partially embodied in symbolic artifacts.

Anyway, in so far as Suchman's formulation refers to the role of plans in the form of artifactually embodied formal constructions in cooperative work, the proposition that "local interactions between the actor and contingencies [...] remain essentially outside of the plan's scope", is debatable, if not simply wrong. The proposition only applies if one disregards, for example, checklists for safety-critical settings that are designed and used to radically constrain local interactions between actor and contingencies, or — as pointed out by Bittner — if one considers these constructions literally.

Different plans in different settings may determine the course of action differently. Plans as formal organizational constructions do not, of course, determine the course of action in any absolute or causal sense but constructions such as standard operating procedures, checklists, charts, forms, schedules, and so forth may certainly determine the course of action in a far stronger sense than a map determines the movements of a traveler. Contrary to Suchman's proposition, we find that, in some fairly widespread cases, formal organizational constructions *control actions,* namely in the sense that they — under conditions of social accountability — serve as stipulations to competent members as to what to do, when, in which sequence etc. and thereby both afford and constrain action and, moreover, that they may be instrumental in conveying these procedural or classificatory stipulations dynamically, in the form of situationally specific instructions.

These are issues that can, and should, be determined empirically, as opposed to philosophically. In other words, for CSCW design purposes we need to investigate the relationship between plan and situated action in far more detail and far more precisely. In particular, we need to understand how pre-specified 'plans' incorporated in artifacts (schedules, forms, etc.) may support practice.

The checklist. First, consider the relatively simple case of the 'normal checklist'.

The checklist is an artifactually embodied protocol that has been deliberately and carefully designed to reduce local control in safety-critical environments. More specifically, a checklist is used to organize tasks whenever it is essential that a list of actions all be performed, typically where it is essential that the actions of the performance be taken in a particular order, in order to ensure a high level of operational safety.

For example, the normal flight-deck checklist indicates a set of different tasks the pilot must perform or verify during all flight segments in order to configure the aircraft and prepare the flight crew for certain 'macro-tasks' such as ENGINE START, TAXI, TAKEOFF, APPROACH, LANDING, etc. For each one of these macro-tasks there are several 'items' to be accomplished and verified by the crew (Degani and Wiener, 1990).

In an analysis of the checklist, Don Norman makes an important observation: "The fact that the preparation of the list is done prior to the action has an important impact upon performance because it allows the cognitive effort to be distributed across time and people" (1991, p. 21). This preparatory task which Hutchins and Norman call "precomputation" can be done when more convenient, e.g., when there is no time pressure and no safety and security risk, and by another actor, e.g., by a specialist. "In fact," Norman observes, "precomputation can take place years before the actual event and one precomputation can serve many applications" (1991, p. 21).

In the case of flight-deck checklists, for example, the process of designing such constructions is quite elaborate. The process begins with the airframe manufacturer who designs the aircraft and determines its operational concept from which the checklist is derived. After the first checklist is designed, it passes through a process of modification and later 'fine tuning' in flight testing. Next, the aviation authorities certifies the checklists as part of certifying the aircraft. Once the aircraft is sold to a particular airline, the second certification process takes place. This certification process is aimed at certifying the carrier to operate the aircraft. In order to prepare for this certification, the fleet manager (or the checklist designer) takes the manufacturer's previously approved procedures and modifies them to coincide with the operational concepts and checklist philosophy of the airline. The checklist is then, again, approved by aviation authorities and when that has happened, it can be used for flight operations. "However, changes and modifications do not stop here; they continue throughout the life of the aircraft in the company." (Degani and Wiener, 1990, pp. 22 f.)

Furthermore, Norman observes, formal constructions such as checklists may serve a "forcing function" in the sense that they, under conditions of social accountability, of course, "force a specific behavior on a person" (1991, p. 34):

> "Automatic behavior is valuable in many skilled operations, for it permits the attention to be directed to one area of concern even while performing smoothly the operations required for another area […]. But at times, it might be valuable to force conscious attention to some aspect of performance by deliberately breaking the activity flow. A good example of a deliberate disruption of activity for safety purposes is the use of checklists in industry and, especially, in commercial aviation. In aviation, the checklist is often reviewed by both pilots, one reading the items, the other confirming and saying aloud the setting of each item as it is read. These actions are intended to force a deliberate, conscious disruption of skilled behavior, deliberately breaking the normal activity flow." (Norman, 1991, p. 24)

The kanban system. Next, consider the kanban system.[21] At Repro Equipment a *kanban* system is used to coordinate certain processes within the Shaping department. As noted above, the shaping department manufactures cabinets from sheet metal. Altogether seven different processes such as cutting, bending, welding etc. are involved. The processes of cutting, bending, welding etc., demand distinctly different machinery and tools, and this means that there are considerable set-up times, from about 15 minutes to less than hour, and each part are therefore produced in lots whose size is defined according to the overall flow and the set-up time on the specific machine. Lot sizes vary from process to process from up to 1,000 in the cutting processes to less than 50 in the welding and the sub-assembly processes. These processes are de-coupled by buffer stocks.

Kanban is a Japanese word meaning 'card' or more literally 'visible record' (Schonberger, 1982, p. 219) and is now used to denote a production control system where a set of cards acts as the coordination mechanism, both as carrier of information about the state of affairs *and* as a production order conveying an instruction to initiate certain activities.

The basic idea is that loosely coupled but interdependent production processes can be coordinated by means of exchanging cards between processes (see Figure 14). A particular card is attached to a container used for the transportation of a batch of parts or sub-assemblies between work stations. When the operator has processed a given batch of parts and thus has emptied the container, the accompanying card is sent back to the operator who produces these parts. Having received the card the operator has now been issued a production order.

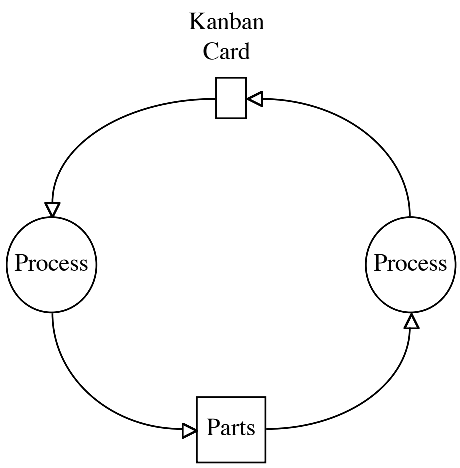

Figure 14. The basic 'syntax' of a kanban system.

The basic set of rules of a kanban protocol are as follows (Schonberger, 1982, p. 224):

(1) No part may be made unless there is a kanban authorizing it.

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[21] Again, this analysis is based on Bjarne Kaavé's findings as reported in his thesis (Kaavé, 1990) as well as in joint analysis sessions with the present author.

(2) There is precisely one card for each container.
(3) The number of containers per part number in the system is carefully calculated.
(4) Only standard containers may be used.
(5) Containers are always filled with the prescribed quantity — no more, no less.

Setting up a kanban system thus requires a careful configuration of the number of containers per part number and the quantity per container. This configuration, in effect, amounts to a precomputation of tasks in terms of batch size per part number, task allocation in terms of work stations for different part numbers, and task sequences.

Aoki (1988) conceives of the *kanban* or just-in-time system as a "semi-horizontal operational coordination mechanism" and argues that this mechanism of coordination is an effective way to adapt a distributed cooperative effort to changing market circumstances quickly without accumulating costly buffer inventories when many varieties comprising a large number of parts are involved. He adds the important observation that the semi-horizontal mode of coordination "crucially depends on the skills, judgment, and cooperation of [a] versatile and autonomous work force on the shop floor", and "a certain degree of blurring of job territoriality between workers on the one hand and foremen, engineers, programmers, etc., on the other".

However, in a *kanban* system, information only propagates 'up-stream' as parts are used down the line. The speed and pattern of propagation of information is severely restricted by the rate and pattern of changes to the field of work at large and the information ultimately conveyed has been filtered and distorted by the successive translations along the line up-stream. The *kanban* system does not provide facilities allowing actors to anticipate disturbances and to obtain an overview of the situation. They are enveloped by an overwhelming and inscrutable quasi-automatic coordination mechanism.

Furthermore, the *kanban* system is not adequate for coordinating manufacturing operations faced with severe demands on flexibility of volume. The *kanban* system can only handle small deviations in the demand for the end product (Schonberger, 1982, p. 227; Monden, 1983). Accordingly, since Repro Equipment is faced with extreme fluctuations in demand, operators recurrently experience that the configuration of the *kanban* system (the number of containers per part number and the quantity per container) is inadequate. In stead of abandoning the kanban system altogether or at least temporarily, they are *change the configuration* in various ways, for example by pocketing a card for time, by leaving card on the fork-lift truck, by ordering new lots before a container has been emptied, by handing cards over directly, by changing lot sizes, etc.

That is, in order to be usable in a setting like Repro Equipment, the kanban system must be managed (monitored, adapted, modified) continually. This is facilitated by the formation of a network of clerks, planners, operators, fork-lift drivers, and foremen in various functions such as purchasing, sales, production, shipping etc. who keep each other informed about the state of affairs so as to control the flow of parts. A member of this network will for example explore the state of affairs 'up-stream' so as to be able to anticipate contingencies and, in case of disturbances that might have repercussions 'down-stream,' issue warnings. That is, the indirect, dumb, and formal *kanban* mechanism is subsumed under a very direct, intelligent, and informal cooperative coordinative arrangement. The cooperative ensemble has 'appropriated' the *kanban* system in order to increase its flexibility. They have taken over control of the system and control the production far more closely and effectively than warranted by the design of the *kanban* system. This is possible only because of their deep knowledge about lead times and inventories in the shaping processes, and the flow of information through the network of what Assembly needs.

Notice that the kanban system might not work like this if it had been designed otherwise, for instance with sensors at the bottom of each container in order to detect and notify automatically when a new production order should be issued. This might make it difficult for operators to change the configuration contingently.

More importantly perhaps, the kanban system is only suitable as a mechanism of interaction because it incorporates (implicitly, in the configuration of the system) a model of pertinent features of the manufacturing operation. Thus, in spite of the fact that the kanban system often is used in situations where it is 'beyond its bounds', it is not discarded but merely modified locally and temporarily according to the requirements of the situation. When an operator pockets a kanban, he is *changing* the configuration of the system, not switching the system off. When the card is put back in circulation, the default configuration is in force again.

However, as a mechanism of interaction the kanban system is defective in that it tied to the field of work in such a way that changes to the state of the kanban system are strongly coupled to state changes in the field of work. The speed and pattern of propagation of information is severely restricted by the successive nodes along the line up-stream. On the other hand, the kanban system allows operators to manage the system in so far as the control of the execution of the protocol is in the hands of the operators: it is the down-stream operator who takes the card and sends it up-stream; it is the truck driver who delivers it; it is the up-stream operator who receives the card and decides to act on it or to deviate from the protocol in some way. That is, due to the operator's control of the execution of the kanban protocol, the direct coupling of the system to the field of work can be severed whenever they deem it appropriate to exercise that control.

Coming back to the issue of the status of formal organizational constructions in cooperative work, the kanban system illuminates several important points:

Suchman's contention that the function of abstract representations such as plans "is not to serve as specifications for the local interactions, but rather to orient or position us in a way that will allow us, through local interactions, to exploit some contingencies of our environment, and to avoid others" is not correct a far as the kanban system is concerned. The arrival of a kanban card is, in Norman's terminology, a forcing function. When an operator receives a card, he or she will produce the batch as specified by the card in accordance with the general rules of the protocol, *without actively searching for reasons not to do so* and without negotiating whether to do so or not.

In their individual activities, actors rely on the kanban system to issue valid and sensible production orders, unless they have strong reasons to believe that its unmitigated execution in the particular situation at hand will have undesirable results. Even then, they do not discard the system but alter its behavior by reconfiguring it, upon which the system is allowed to 'switch back' to the default configuration.

That is:

- Actors coordinate their distributed activities by *executing* the protocol — *unless* they have strong reasons to believe otherwise.
- When actors have reasons to doubt the rationality of executing a production order issued by the system, they reconfigure the system or respecify the protocol temporarily by withholding cards or introducing false cards.
- By reconfiguring the system, actors do not discard the system but alter its behavior temporarily, upon which the system is allowed to switch back to its default configuration.

The kanban system thus determines action a far stronger sense than the map of a traveler determines the traveler's movements (Suchman, 1987, p. 188 f.; Bucciarelli, 1988, p. 114). In the *kanban* case the protocol conveys a stipulation in the form of a production order to the particular actor instructing the actor, under the conditions of social accountability, to take the actions specified by the card according to the general rules of interpretation laid down in the protocol. It is more like a script than a map. In fact, the kanban system works well even though it does not provide a 'map' in the form of an overview of interdependencies among processes.

The point is that the kanban protocol under normal conditions of operation relieves actors of the otherwise forbidding task of computing myriad — partly interdependent, partly competing — production orders and negotiating their priority. They can, for all practical purposes, rely on the precomputed protocol to issue valid production orders; they take it for granted. Thus, for an actor in Repro Equipment to question the rationality of the protocol at every step in every situation would be an utter waste of effort, and it does not happen.

What formal organizational constructions such as protocols do can be expressed in a slightly different manner by using Don Norman's term 'semantic distance'. According to Norman, semantic distance is the relationship between the user's intentions and the meaning of the expressions that are possible in the "interface language" (Norman and Hutchins, 1988). In other words, the larger the number of operations required to achieve a particular state, the greater the semantic distance. Thus, a checklist may reduce semantic distance by simplifying the task of configuring the aircraft for the next flight segment:

> "Even the simple checklist reduces the semantic distance for its users. Lacking the checklist, the novice must discover the steps that need to be done and an order in which they can be applied. With the checklist, the task is transformed: reading and following instructions take the place of procedural reasoning." (Norman and Hutchins, 1988, p. 15)

As a generalization, we find that a protocol stipulates the articulation of distributed activities by conveying affordances and constraints to the individual actor which the actor, as a competent member of the particular ensemble, can apply without further contemplation and deliberation unless he or she, again as a competent member, have accountable reasons not to. That is, actors deviate from the stipulations of the protocol if and when they have compelling reasons to do so, and only then.

In this conception, protocols are not, strictly speaking, representations (Suchman, 1987, p. 186) but performative constructs (Bowers, 1993). They do not describe action; they offer precomputed prescriptions for it.

Formal organizational constructions such as plans, conventions, procedures, and so forth play different roles in cooperative work. They may, on one hand, play a 'weak' role of the map of the traveller by providing a codified set of functional requirements pertinent for the effort in question which provides a general heuristic framework for distributed decision making. On the other hand, they may play the 'strong' role of a protocol that offers a 'precomputation' of interdependencies among activities (choices, sequential constraints, temporal constraints, etc.) which, for each step, provides instructions to actors of possible or required next steps. Which role is appropriate depends on the extent to which it is possible to identify, analyze, and model interdependencies in advance.

Moreover, the role of a particular formal construction may vary according to the situation. Thus, in a situation where a standard operating procedure does not apply, the procedure may merely serve in its default capacity as a vehicle of conveying heuristics (as, for instance, in the the accounting office analyzed by Suchman). In other cases, however, such as the kanban case, the role of the protocol does not vary in face of contingencies; rather, because of the complexity of the interdependencies of discrete parts production, the kanban protocol is not discarded, suspended, nor 'weakened' but temporarily respecified (reconfigured) by operators to accommodate the passing disturbance.

4.2.3. The inherent vagueness of protocols

As pointed out by Suchman, protocols are inexorably characterized by "the inherent and necessary under-specification of procedures with respect to the circumstances of particular cases" (Suchman, 1982, p. 411). Furthermore, Suchman observes, "the vagueness of plans is not a fault, but is ideally suited to the fact that the detail of intent and action must be contingent on the circumstantial and interactional particulars of actual situations" (Suchman, 1987, pp. 185 f.) However, the degree of vagueness of specific plans is itself contingent:

> "While plans *can* be elaborated indefinitely, they elaborate actions just to the level that elaboration is useful; they are vague with respect to the details of action precisely at the level at which it makes sense to forego abstract representation, and rely on the availability of a particular embodied response." (Suchman, 1987, p. 188)

Thus, it is not only that a protocol, as a linguistic construction (Suchman, 1987, p. 186), is inherently vague compared to the rich details of the actually unfolding activities of the cooperative work arrangement in which it is applied, but a protocol is deliberately under-specified with respect to (1) factors that are immaterial for the purpose to be served by the given protocol or (2) factors that can more efficiently and effectively be left unspecified until a later stage.

Consider, for example, the case of the International Classification of Diseases:

The International Classification of Diseases (ICD) is an example of a list that mediates and coordinates cooperative work between specialists (Bowker and Star, 1991). As opposed to the unassuming list of shares, it is not — as an artifact — simple nor is its cooperative management merely a matter of deciding whether a certain entity should be included or not. Rather, the ICD is a classification scheme that has evolved over very long time, it is being developed by a large number of people with incongruent objectives and perspectives, and it serves to coordinate a vast number of widely distributed activities in quite different circumstances.

The ICD is a list of causes of death and diseases. It is about one hundred years old, and has been revised nearly every ten years since the 19th century. The ICD is typically distributed as a book to public health offices, hospitals, and bureaus of vital statistics throughout the world. It contains numbers which correspond to causes of death or illness, and algorithms for arriving at those numbers in complex cases involving more than one disease or cause.

> "One of the values of a list like the ICD is that it can be used in trans-national comparisons. This is useful epidemiologically, in that it enables one to trace specific environmental and nutritional factors that might be involved in the occurrence or spread of particular diseases." (Bowker and Star, 1991, p. 75)

However, these advantages can only be fully exploited if the various states agree on the way information is collected and coded. Different states submit their data more or less promptly; they have different administrative structures with different units of aggregation; and they have different policies concerning death certificates that have made an appreciable difference to the results of the ICD.

In addition, different categories of users of the ICD (such as doctors, epidemiologists, and statisticians) have different needs and pose conflicting demands on the design of the ICD. And, finally, similar conflicting demands are posed by various industrial actors: insurance companies, industrial firms, and pharmaceutical companies.

The point is, in the words of Bowker and Star, that "the list cannot be homogeneous, neutral and appeal to all parties" (Bowker and Star, 1991, p. 77).

As established by Bowker and Star, the design and use of the ICD has been adapted to these requirements in many ways, most importantly by means of the following features:

Residual categories. These categories can indicate uncertainty at the level of data collection or interpretation. Forcing a more precise designation could give a false impression of positive data. The major disadvantage is that a lazy or rushed doctor will be tempted to overuse 'other'.

Heterogeneous lists. Throughout the history of the ICD, there has been a great deal of debate about whether it constituted a nomenclature or a classification. The difference is that a nomenclature is merely a list which does not give any indication of cause whereas a classification gives causes. The advantage of a nomenclature is that it can remain more stable over time whereas classifications are more convenient immediately, but change frequently. In the words of Bowker and Star, "the solution that has emerged over time has been rather to find the appropriate level of ambiguity — to keep the list as heterogeneous as possible for the different actors to find their own concerns represented." (Bowker and Star, 1991, p. 77)

Parallel different lists. Different user groups have found that the ICD did not serve their purposes, and so they have modified it. This could for instance happen in a country with a different range of medical problems. Similarly, some specialists might be interested in a finer breakdown than that permitted by the ICD. The strategy of the ICD committee in these cases has been to issue rules for how the list is to be modified.

Bowker and Star draw four lessons from their study of the ICD that are worth quoting:

> "- first, there is a permanent tension between attempts at universal standardization of lists, and the local circumstances of those using them;
>
> - second, this tension should not, and cannot, be resolved by imposed standardization, because the problem recurses;
>
> - third, rather, from the point of view of coordination, ad hoc responses to standardized lists can be mined for their rich information about the heterogeneous knowledge domain [...];
>
> - fourth, making this sort of list is an example of the creation of the sort of object which must satisfy members of worlds or organizations with conflicting requirements. In its creation, and later in its use, the complex list is a kind of knowledge representation particularly useful for coordinating distributed work, which often contains requirements of this sort. Some, ourselves among them, would argue necessarily conflicting." (Bowker and Star, 1991, p. 74)

That is, the collection, organization, and use of data pertaining to causes of death at a global scale is a cooperative effort on a vast scale and involving multitude of interested parties. The whole enterprise hinges on a globally accepted, standardized classification scheme, the ICD that is managed cooperatively — by the committee as well as by the data providers and users. However, the adoption of a standardized classification scheme does not alleviate the conflicting demands and needs. "The problem recurses." To handle that, the design and management of the list adapts to the conflicting demands by carefully finding "the appropriate level of ambiguity".

Let us pursue the notion of the appropriate level of vagueness further *as an issue of design*. First, consider the simple checklist again. As observed by Degani and Wiener, the issue of the level of granularity is a crucial issue in the design of a checklist:

> "The matter of which items should be presented on the checklist is a cardinal question in checklist philosophy. Some will argue that most of the configuration items required in operating the aircraft must be presented in the checklist. Others will argue that since the checklist is a redundant task, only the critical and most important items should be presented on the checklist. This statement leads to another controversy — which items are critical and important enough to be registered on the checklist." (Degani and Wiener, 1990, p. 20)

That is to say, the level of granularity is a design issue influenced by a host of factors: the level of cockpit automation, how frequently the checklist is used, the perceived risks involved as well as issues of managerial policy, etc. (ibid., pp. 20-22).[22]

Next, consider the S4000 project again. The mechanisms of interaction that were developed and used in the S4000 project (e.g., the bug form, the platform period schedule, the augmented bill of materials) denote actors by identifying roles. The bug form, for instance, only identifies the software designer to be responsible for verifying a bug reported as corrected by giving the platform period number. The name of the software designer that will be platform master for the particular platform period is identified in the project schedule, but can be left pending until the platform period is imminent.

Similarly, the deadline for the correction is not explicitly stated in the bug form but is, again, inferred from the reference to the platform period which in turn refer to the project schedule spreadsheet where the deadline is stated explicitly (Borstrøm et al., 1995). This example indicates that the definition of a protocol can subscribe not only to role definitions but to definitions or specifications of any variable or attribute. Because of this, actors may not need to specify explicitly what can be inferred, for example from other mechanisms, at some point in time. (for a more through discussion of the issue of interacting mechanisms of interaction, cf. Schmidt et al., 1994).

As local and temporary closures, well-designed protocols should be conceived of as specialized protocols with a bounded jurisdiction. Protocols only specify what is pertinent for their purpose and then only to the degree of explicitness that is deemed necessary. The missing specifications are then filled-in as they are instantiated in the course of the work.

The double under-specification of protocols also means that the ways and means of instantiating the protocol can be quite open. As pointed out by Strauss,

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22 There is also the issue of badly designed checklists, of course. As noted by Degani and Wiener, the checklist "becomes a 'dumping site' to resolve discipline problems, and/or to show management and regulating officials that a specific problem is settled. By placing these type of item(s) on the checklist, immediate problems may be resolved, but the importance attached to the procedure by the pilots is reduced, leading to additional and possibly even more severe problems." (Degani and Wiener, 1990, p. 24)

> "tasks can be imposed; they can be requested; also they can just be assumed without request or command; but they can also be delegated or proffered, and accepted or rejected. Often they are negotiated. And of course actors can manipulate openly or covertly to get tasks, or even have entire kinds of work allocated to themselves." (Strauss, 1985, p. 6)

That is, a protocol and the whole equipage of ensuing stipulations can be invoked implicitly, without any explicit announcements, for instance by certain actors taking certain actions.

This point was illustrated quite vividly in a study by Thomas Schäl of the use of The Coordinator in an occupational training organization in the Lombardy region of Northern Italy (Schäl, 1994). The Coordinator was generally considered a good solution for communication needs in that it provided advanced email functionality, whereas the core functionality of the system was used by only a few. That is, most of the actors merely utilized The Coordinator as an enhanced email system, without the underlying conversation structure. Schäl identifies several different and sometimes contradictory reasons as to why actors in this case did not use the protocol. In some cases, the reason for not using the underlying protocol is similar to the established critique of The Coordinator. For example, some of the informants found the conversation protocol inadequate because is assumes that roles and commitments are clearly defined. In other cases, however, the reasons for not using The Coordinator are surprising from the standpoint of conventional wisdom in CSCW. For example, to some of them the notion of sending a 'request' to another was perceived as inappropriate, especially if the recipient was superior in rank to the sender. Similarly, other actors did not use the conversation protocol because they, in their particular jobs, did not want to invite negotiations, for instance about deadlines!

In an interesting discussion of these findings Schäl points out that commitments are not always stated explicitly; they rather follow implicitly from the context of the task at hand and the wider context of the setting:

> "Commitments in processes are defined by the simple fact that somebody has to deliver something to somebody else as foreseen. This leads to the identification of client/supplier chains in the working process. What has to be negotiated are the conditions under which the commitments among clients and suppliers are accomplished." (Schäl, 1994)

And, perhaps more importantly, Schäl makes the astute observation that the wider context from which commitments are inferred is to a very large extent constituted by — protocols: "without defined processes and roles there are no implicit commitments for persons involved which can be made explicit by using The Coordinator" (Schäl, 1994).

Thus, situated action is the context in which protocols are played out. And, conversely, protocols are the context in which situated action is played out.

4.3. Artifacts as constraining vehicles

Which role does artifacts play in conveying stipulations in cooperative work?

Since there has been much controversy concerning the nature of artifacts, we need to start by addressing the issue of the nature of artifacts.

Being an artifact is not a structural, material, geometrical, behavioral etc. property of the thing itself but a certain social status: an artifact is, as Jacques Monod aptly puts it, an object "endowed with a purpose" (Monod, 1972, p. 19).[23]

As an object endowed with a purpose, the artifact's structural, material, geometrical, behavioral etc. properties have been deliberately adapted to serve this specific purpose under specific conditions.

> "An artifact can be thought of as a meeting point - an 'interface' in today's terms - between an 'inner' environment, the substance and organization of the artifact itself, and an 'outer' environment, the surroundings in which it operates. If the inner environment is appropriate to the outer environment, or vice versa, the artifact will serve its intended purpose." (Simon, 1981, p. 9)

The purpose of, say, a clock, to use the example discussed by Simon (1981, pp. 8 f.), is to 'tell time'. The mechanism (gears, springs etc.) of the clock is the 'inner environment' enabling it to fulfill this purpose. The specific conditions of the 'outer environment' in which the artifact is to fulfill its purpose, entails specific requirements to the 'inner environment', however. The design of the 'inner environment' must meet these specific requirements if the clock is to be able to fulfill its purpose in the specific conditions of the 'outer environment'. Sundials may perform well in a sunny climate, but not in the Arctic winter. Likewise, the 'inner environment' of a clock that is to be able to perform under the conditions of the 'outer environment' of a ship must meet another set of specific requirements. "The outer environment determines the conditions for goal attainment" (Simon, 1981, p. 15)

For artifact to serve its *purpose*, it must able to perform under the *specific conditions* of the 'outer environment' in which the purpose is to be achieved. Thus, to the designer, the purpose and the conditions of the 'outer environment' are interlinked. One does not merely design a clock, one designs a clock to 'tell time' under specific conditions. To express this linkage between purpose and specific conditions, Newell and Simon use the term 'task environment': "The term *task environment* [..] refers to an environment coupled with a goal, problem, or task" (Newell and Simon, 1972, p. 55).

In his classic study of design, Christopher Alexander makes the identical point: "every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem" (Alexander, 1964, p. 15). "Fitness is a relation of mutual acceptability between these two." (Alexander, 1964, p. 19). A 'good fit' is obtained through carefully balancing the contradictory and interdependent de-

23 "In fact, on the basis of structural criteria, macroscopic ones, it is probably impossible to arrive at a definition of the artificial which, while including all 'veritable' artifacts, such as the products of human industry, would exclude objects so clearly natural as crystalline structures, and indeed, living beings themselves which we would equally like to classify among natural systems" (Monod, 1972, p. 19).

mands posed by the task environment and configuring the inner environment accordingly.

As an object endowed with a purpose and deliberately adapted to serve this purpose under the conditions of the task environment, *an artifact is a vehicle for a social relationship*, namely the relationship between its designer and its user. In endowing the artifact with a purpose, the designer furnishes the object with a set of properties that constrain the degrees of freedom of its use and thereby adapts its inner environment to the intended task environment. In other words, *an artifact can be conceived of as a social relationship of purposive constraints embodied in the specific properties of an object*.[24]

In this conception, then, artifacts can be conceived of and analyzed as vehicles that quite purposively convey certain constraints to the behavior of the actor.

Phenomenologically, however, that is, to the practical as opposed to the theoretical apperception, the purpose with which the artifact is endowed and the premeditated configuration of its inner environment, recedes into the background. Thus, in Heidegger's analysis, an artifact is essentially "something in-order-to" (Heidegger, 1927, p. 68):

> "An artifact can genuinely show itself only in dealings cut to its own measure (hammering with a hammer, for example). [...] The hammering does not simply have knowledge about the hammer's character as an artifact, but it has appropriated this artifact in a way which could not possibly have been more suitable. In dealings such as this, where something is put to use, our concern subordinates itself to the 'in-order-to' which is constitutive for the artifact we are employing at the time; the less we just stare at the hammer-Thing, and the more we seize hold of it and use it, the more primordial does our relationship to it become, and the more unveiledly is it encountered as that which it is — as artifact. The hammering itself uncovers the specific 'manipulability' of the hammer."(Heidegger, 1927, p. 69)[25]

That is, the properties of the artifact are taken for granted by the skilled worker whose conduct has long since been seamlessly adapted to the inherent constraints of the artifact; his or her handling of the artifact is formed in accordance with the specific configuration of degrees of freedom provided by the artifact ("auf das Zeug zugeschnittene Umgang") and wields it in "*in a way which could not possibly have been more suitable*".

Thus, it is not that "our use of artifacts is what they mean to us" (Ehn, 1988, p. 65).[26] It is rather that our use of the artifact is carefully constrained by the pre-

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24 In Marx' economic theory, 'value' is conceived of as a social relationship mediated by a thing, namely by the specific commodity in question (Marx, 1867). The difference is that the commodity is a mere container of a quantity of 'dead labor' and that its specific properties as a useful artifact are irrelevant (provided the artifact has a 'use value'), whereas it is the specific functional properties of the artifact in which its purpose is endowed that convey the social relationship of purposive constraints.

25 The English translation of Heidegger's text is based on the translation by Macquarrie and Robinson (Heidegger, 1962, p. 98).

26 Notice that Heidegger's analysis of the practical mind's encounter with artifacts is often misrepresented in the literature and is given renditions that leave the impression that an artifact is whatever an actor seizes on and uses. Following Macomber (1967), Michael Lynch, for example, ascribes Heidegger an almost subjectivistic position: "Rather than defining the artifact by reference to a historically prior creative purpose, Heidegger expresses a relation of 'ready to hand' as an appresentative constituent of

meditated configuration of degrees of freedom embodied in the artifact and that these constraints are transparent to us when using the artifact. By taking the constraints for granted we act "in a way which could not possibly have been more suitable".

For our purpose, the validity of this phenomenological interpretation of use of artifacts is quite limited, however. It is based on an analysis of craft-like skills[27] and thus falls down as soon as one considers work domains which are characterized by complex technical systems (manufacturing plants, power plants and grids, urban mass transport systems, aircraft, airports, air traffic control systems, telephone networks, operating theaters and intensive care units, etc.) and other complex work settings (banks, hospitals, etc.). Surely, work in such settings inexorably involves aspects of craft skills, but competent actors cannot not rely on "hammering itself" for uncovering the specific "manipulability" of the artifact. To the contrary, in such settings, competent conduct requires theoretically founded conceptualizations of the complex artifacts.[28]

In this context, however, the point is that artifacts — the most mundane tools such as hammers as well as the most complex — are useful (inter alia) because *they are 'closures'* in the sense that they restrict the space of possibilities faced by actors in a way that 'fits' the specific task environment.

4.3.1. Symbolic artifacts as constraining vehicles

Let us now leave the general discussion of physical artifacts and their computer-based counterparts and, more pertinent to the purpose of this analysis, consider the class of *symbolic or cognitive artifacts*[29], that is, artifacts that are not part of the field of work (as tools are) and yet are instrumental in reducing the complexity of work by providing some kinds of constraints to the conduct of the actor. Ed Hutchins calls such artifacts 'mediating structures'[30]:

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artifact. […] The artifact is […] shown to be a feature of the encounter rather than of any independent characteristics of the object." (Lynch, 1985, pp. 123 f.).

27 The examples discussed by Heidegger are remarkably dated; the entire discussion reads like an inventory of artifacts from a medieval Bavarian village: hammer, plane, needle, etc. (Heidegger, 1927, pp. 67-71).

28 The issue of highly complex artifacts becomes acute in Winograd and Flores' rendition in which Heidegger's analysis of the practical mind's encounter with artifacts is interpreted as an analysis of unconscious manual routines: "In driving a nail with a hammer (as opposed to thinking about a hammer), I need not make use of any explicit representation of the hammer. My ability to act comes from my familiarity with *hammering*, not my knowledge of a *hammer*" (Winograd and Flores, 1986, p. 33). "To the person doing the hammering, the hammer as such does not exist. It is part of the background of *readiness-to-hand* that is taken for granted without explicit recognition or identification as an object. It is part of the hammerer's world, but is not present any more than are the tendons of the hammerer's arm. The hammer presents itself as a hammer only [sic!] when there is some kind of breaking down or *unreadiness-to-hand*" (Winograd and Flores, 1986, p. 36).

29 In Norman's definition, "a cognitive artifact is an artificial device designed to maintain, display, or operate upon information in order to serve a representational function" (Norman, 1991, p. 17).

30 In fact, Hutchins uses the term 'mediating structures embodied in artifacts.' For Hutchins, mediating structures are not necessarily artifactual. His discussion focuses on mediating structures embodied in artifacts, however.

> "I take *mediation* to refer to a particular mode of organizing behavior with respect to some task by achieving coordination with a mediating structure that is not itself inherent in the domain of the task. That is, in a mediated performance, the actor does not simply coordinate with the task environment, instead, the actor coordinates with something else as well, something that provides structure that can be used to shape the actor's behavior." (Hutchins, 1986, p. 47)

For example, consider the checklist again. The checklist can be conceived of as an artifactually embodied 'mediating structure' that has been deliberately and carefully designed to reduce local control, typically in safety-critical environments:

> "In order to use a checklist as a guide to action, the task performer must coordinate with both the checklist and the environment in which the actions are to be taken. Achieving coordination with the checklist requires the actor to invoke procedures for the use of the checklist. These include reading skills and a strategy for sequential execution which permits the task performer to ensure that the steps will be done in the correct order and that each step will be done once and only once. The fixed linear structure of the checklist permits the user to accomplish this by simply keeping track of an index that indicates the first unexecuted (or last executed) item. Real checklists often provide additional features to aid in the maintenance of this index: boxes to tick when steps are completed, a window that moves across the checklist, etc. The mediating artifact has been designed with particular structural features that can be exploited by some procedure to produce a useful coordination." (Hutchins, 1986, pp. 47 f.; cf. also Norman and Hutchins, 1988, p. 9)

Mechanisms of interaction can be conceived of as a special case of 'mediating structures', namely artifactually embodied 'mediating structures' that are used to *constrain the articulation of distributed activities* in cooperative work settings.

In his analysis of cognitive artifacts, Norman introduces a distinction between 'surface representation' and 'internal representation' which is important for the analysis of mechanisms of interaction:

> "Some artifacts are capable only of a surface level representation. Thus, memory aids such a paper, books, and blackboards are useful because the allow for the display and (relatively) permanent maintenance of representations. […] These devices are primarily systems for making possible the display and maintenance of symbols: They implement the 'physical' part of the physical symbol system. These are called *surface representations* because the symbols are maintained at the visible 'surface' of the device — for example, marks on the surface, as pencil or ink marks on paper, chalk on a board, indentations in sand, clay or wood. […] Artifacts that have internal representations are those in which the symbols are maintained internally within the device (unlike paper and pencil where the symbols are always visible on the 'surface'). This poses an immediate requirement on the artifact: There must be an interface that transforms the internal representation into some surface representation that can be interpreted and used by the person." (Norman, 1991, p. 25)

Analyzing paper-based mechanisms of interaction (checklists, kanban systems, bug report forms, etc.) from this perspective, poses the obvious problem that such artifacts *are* surface representations and do not have internal representations (they do not have wheels and gears and chips); the 'internal representations' that can be ascribed to the protocol is not incorporated in the artifact, they are exclusively handled by the actors. If we consider the mechanism of interaction as a whole and abstract from the specific allocation of functionality between actor and artifact, we can make some useful observations:

The 'surface representation' of the checklist provides an adequate interface to the 'internal representation': the sequence of the tasks prescribed by the protocol is represented graphically in the 'fixed linear' form of a list and for each task there may be a check box or some other index for marking steps that have been executed and thus to indicate the state of execution of the protocol.

Similarly, the 'surface representation' of the kanban system is the set of inscribed cards whereas the 'internal representation' is the specific configuration of the system and the general rules for handling the system; in other words, the 'internal representation' is the kanban protocol as instantiated in the particular setting. The state of the protocol is not displayed in the appearance of each card, however, and state changes to the protocol under execution can not be inferred from the inscription on the cards. The only interface to the state of the protocol is the *location* of the multitude cards in the distributed manufacturing system.

In the bug form mechanism, on the other hand, the state of each reported bug is reflected at the 'surface' by the successive inscriptions on the form made by different actors and in the compilation of bug forms in publicly available repository ('the binder'). This facility makes the bug form a vehicle of *mediating* as well as of *stipulating* articulation work — an issue we will revert to below.

The study of airline operations room by Suchman and Trigg (Suchman and Trigg, 1991) illustrates very clearly the delicate issues involved in designing appropriate surface representations. The operations room is a communications center that coordinates the ground operations of a single airline. The employees are responsible for getting planes into and out of gates and for transferring baggage and passengers between planes. Their effort are "especially concerted" during "complexes", that is, periods when transfers are to be made between multiple incoming and departing flights. Each complex lasts for about an hour and there are eight complexes in a normal workday. In order to be able to coordinate the transfers during complexes, the actors use the airport's computer system as well as artifacts called "complex sheets."[31] The complex sheet is, basically, a matrix that maps incoming to departing planes and for each cell gives the number of passengers and baggage items to be transferred between them:

> "The dynamic nature of the complex is captured on the sheet by ordering the rows and columns of the matrix chronologically. Thus an Ops Room member checking off completed transfers should generally be moving diagonally downward and to the right across the cells of the matrix. Delayed flights display themselves as groups of cells left behind in this process." (Suchman and Trigg, 1991, p. 68)

On one evening, the Ops Room had to handle one airplane arriving at gate 18 during complex 7 and departing from gate 14 during complex 8, an hour or two later. As observed by Suchman and Trigg, the complex sheet gives rise to problems when actors are faced with this kind of situation:

> "The dynamics of the complex in question […] present problems for these established procedures. The major problem is that the aircraft swap takes place across two successive com-

31 A specimen is reproduced in (Suchman and Trigg, 1991, p. 68).

> plexes, and thus stretches the complex sheet design in various ways." (Suchman and Trigg, 1991, p. 68)

That is, the surface representation of the complex sheet is experienced to be problematic in such situations. In view of this, one of the actors suggests a simple device for denoting a plan swap across two complexes: "I should have put eighteen slash fourteen on there" (Suchman and Trigg, 1991, p. 69).

Jack Goody's analysis of the differences and the interfaces between oral and written modes of interaction is quite pertinent for understanding what is gained (and lost) by embodying protocols in symbolic artifacts. As noted above, in the discussion of different modes of interaction, written artifacts are, in principle, accessible to any member of the ensemble, whatever its size and distribution in time and space and they can therefore be marshaled at any time as a referential for clarifying ambiguities and settling disputes. They are, for all practical purposes, unceasingly publicly accessible.

Furthermore, the written medium encourages the decontextualization or generalization of stipulations of orderly cooperative work. In their very nature, written stipulations have been abstracted from particular situations in order to be addressed to the target audience in general, rather than delivered face-to-face to a specific group of people at a particular time and place (Goody, 1986, pp. 12 f.). Moreover, discussing the specific affordances provided by the surface representation of written text, Goody observes that writing introduces certain spatio-graphic devices such as lists, tables, matrices by means of which linguistic items can be organized in abstraction from the context of the sentence (e.g., in thesauri):

> "We find, for example, a large number of lexical lists, of trees, roles, classes of various kinds, which possess several characteristics that make them differ from the categories that usually emerge in oral communication. First, they consist of isolated lexemes abstracted from the flow of speech, and indeed from almost any 'context of action' except that of writing itself. Secondly, they are formalized versions of classificatory systems that are to some degree implicit in language use but go beyond those classificatory systems in important ways. In particular they take category items out of the sentence structure, and group them by similarities, sometimes even providing them with unpronounced […] class indicators. Thus the categories are given a formal shape, a specific beginning and a definite end, into which each item has to fit […]. Moreover the boxes tend to be exclusive. Fruits end here; vegetables begin there; the tomato has to be placed in one box or table rather than another, setting aside […] the flexibility of oral usage which has greater toleration of ambiguity and anomaly, a greater contextualization. But the very absence of such toleration may raise interesting questions in the mind (and the pen) of the person forced to choose between placing an item in one box rather than another. As is the case with other written procedures, the notion of 'contradiction' is sharpened." (Goody, 1987, p. 275).

That is, the spatio-graphic surface representation of a symbolic artifact can be used to constrain behavior by reminding an actor of items to do and directing attention to missing items: "The table abhors a vacuum" (Goody, 1987, p. 276). This is eloquently illustrated in the case of the flight strip, the bug form, and the augmented bill of materials.

By way of concluding this discussion, it is important to keep in mind that an artifact only conveys stipulations within a certain social context, within a certain community, in which the protocol and any change to the state of the protocol have a (more or less) certain and agreed-to meaning and that it only does so under conditions of social accountability. The point we want to make here, however, is that the specific structural and behavioral properties of the artifact (its surface representations as well as its internal representations, if such have been incorporated in the artifact) are formed to serve the purpose of conveying specific stipulations within this particular context by constraining and forcing the actors' behavior.

4.3.2. Symbolic artifacts as vehicles mediating articulation work

Consider, for example, the bug form mechanism again. As noted above, the state of each reported bug is reflected in the successive inscriptions on the form made by different actors. That is, a change to the state of the protocol induced by one actor (a tester reporting a bug, for example) is conveyed to other actors by means of a change to the state of the surface representation of the form itself; furthermore, this change is propagated within the ensemble according to the stipulations of the protocol, and the state of the total population of reported bugs is publicly visible in the public repository of bug forms ('the binder').

Similarly, in the case of the kanban mechanism, the artifact — the collection of cards in circulation — mediates articulation work in the sense that the change of location of a card, that is, the fact that it is transferred from one actor to another 'up-stream', is equivalent to the arrival of a production order at that work station.

In these cases, the artifact not only stipulates articulation work (like a checklist) but *mediates articulation work as well in the sense that the artifact act as an intermediary between actors that conveys information between them about state changes to the protocol under execution*. By serving the dual function of stipulating and mediating articulation work, the artifact is instrumental in reducing the complexity of articulating a vast number of interdependent and yet distributed and perhaps concurrently performed activities.

This conception of an artifact mediating articulation work is not identical to Hutchins' concept of 'mediating structures'. For Hutchins, the artifact or structure serves as an intermediary between an actor planning or defining the protocol for an activity and the actor performing the activity; that is, he uses the term 'mediate' to denote what we have termed 'stipulate' (Hutchins, 1986). We reserve the term 'mediate' to denote an artifact serving as an intermediary of *horizontal* propagation of state changes to the protocol.

Finally, when we consider symbolic artifacts that mediate articulation work — as opposed to the more general case of 'mediating structures' that stipulate work in general — another aspect of the 'surface representation' becomes crucial, namely that it has a standardized format. That is, the 'surface' of the artifact must have a standardized format in order for the state of the protocol as displayed 'at the surface' to be apperceivable 'at a glance' and, in effect, genuinely publicly available. The flight strip and the bug form are both illustrative cases of this requirement.

4.4. Allocation of functionality between actor and artifact

There is a wide spectrum of degrees of 'local control' of articulation work from, at the one end, modes of interaction that do not involve any pre-specified stipulations — to modes of interaction that involve protocols incorporated in symbolic artifacts at the other end of the spectrum:

(1) *Ad hoc articulation* (by means of monitoring others, directing attention, negotiating, etc.). This mode of articulation work offers a high degree of local control and hence very powerful means of recovery from misunderstanding and error and of handling contingencies. On the other hand, ad hoc articulation is highly inefficient when faced with recurring problems, and it may be difficult to anticipate the course of the cooperative effort and hold actors accountable.

(2) Articulation by means of *conventional protocols*, i.e., the usual and expected way to do things. Whether the conventions are made explicit or merely observed tacitly, this mode wholly relies on actors' varying interpretations and recollections of the stipulations of the convention while in the midst of the work, 'in the fog of war'. Without a durable and publicly available referent, it may be difficult to hold actors accountable in case of possible deviations from stipulations.

(3) Articulation by means of prescribed protocols supported by *linguistic artifacts in the* form of *written statutes*, e.g., standard operating procedures or accounting prescriptions. As opposed to conventions, stipulations supported by artifacts in the form of written statutes are, in principle, accessible by all at any time. That is, the fact that the stipulations are supported by symbolic artifacts makes actors accountable in a far higher degree. In addition, the text of the statute is accessible to any actor in the course of action and can therefore be consulted in case of uncertainty. Apart from such consultations, the execution of the stipulation relies completely on actors' interpretation of and recollection of the stipulations of the procedure (Hart, 1961; Goody, 1986).

(4) Articulation by means of prescribed protocols supported by *formatted artifacts* which provide a (for the duration of the execution of the protocol) permanent iconic (graphical, structural, temporal, auditory, etc.) representation of pertinent features of the underlying protocol and from which actors can obtain an overview of the protocol as well as a guide in a particular situation, e.g., checklists, time tables, organizational charts, classification schemes for repositories. In these cases, the execution of the protocol no longer relies completely on actors' recollection of the protocol and the range of (reasonable) interpretation is relatively narrow compared to, say, statutes.

(5) Articulation by means of prescribed protocols supported by *formatted artifacts* which *constrain* the discretion of actors by imposing a standardized iconic (graphical, structural, temporal, auditory, etc.) representation of pertinent features of the underlying protocol as a template for local activities, e.g., bug report forms.

(6) Articulation by means of prescribed protocols supported by mutable artifacts which represent, dynamically, the state of the execution of the protocol and

thereby convey information pertaining to the state of the execution of the protocol between actors, e.g., a kanban system.

(7) Articulation by means of prescribed protocols supported by mutable artifacts which convey information pertaining to the state of the execution of the protocol between actors in a (partly) *mutable form* by making the state of the protocol immediately visible on the 'surface representation' provided by the artifact, e.g., the bug form, the augmented bill of materials, workflow management systems.

5. Requirements for computational mechanisms of interaction

What are the implications for CSCW systems design? CSCW systems have generally failed to meet the requirements of users in actual cooperative work settings, primarily due to constraints imposed by current operating system designs. It is becoming increasingly clear that current operating systems in important ways are inadequate as operating systems for CSCW systems. They are deficient for CSCW purposes in that they do not adequately support the seamless interweaving of individual and cooperative activities; the repertoire of alternative modes of interaction; the fluent and dynamic meshing of the available repertoire of modes of interaction; or the deeply material situatedness of articulation work, i.e., the fact that cooperative work is inextricably articulated with reference to the state of the field of work.

5.1. General requirements for CSCW environment

Cooperative and individual activities are inextricably interwoven in daily work practice.

First, the boundary between individual and cooperative work is dynamic in the sense that people enter into cooperative work relations and leave them according to the requirements of the current situation and the technical and human resources at hand. That is, cooperative work arrangements emerge contingently, to dissolve again into individual work.

Second, in cooperative work settings, cooperative activities are punctuated by individual activities and vice versa. People shift between individual and cooperative activities and, while engaged in cooperative activities, they may be simultaneously involved in parallel streams of activity conducted individually.

Third, cooperative work is always conducted by individuals, and conversely, in cooperative work settings individual activities are always penetrated and saturated by cooperative work (Hughes et al., 1991; Heath and Luff, 1992; Heath et al., 1993). An activity carried out individually may be — or may any time become — part of a wider, loosely coupled cooperative activity.

A CSCW system should thus support the fluent meshing of individual and cooperative activities. In all its generality, this statement may seem uncontroversial. Nevertheless, most of the existing CSCW software products do not support this fluency. For example, when composing an email message the user should not be required to shift to a special editor and leave the word processor normally used for composing letters, writing reports etc. The same applies to CSCW facilities supporting cooperative authoring, conferencing, etc. The commercial groupware product ASPECTS, for example, allows multiple users to cooperate on writing a document. However, they are required to leave their single-user word processor and shift to the word processing facility of ASPECTS in order to cooperate. The effect of this that the system creates an impedance between cooperative and individual activities.

Since the *means of communication* required by the modes and mechanisms of interaction are semantically neutral in the sense that they can be applied (with different scope) in articulation work in all work domains, we will argue that these means of communication *should be conceived of as functions of the extended operating system*. That is, CSCW facilities that support cooperative work by supporting various modes of interaction by increasing the bandwith of the communication channel or by reducing the turnaround time should not be conceived of as applications or be implemented as part and parcel of applications but as *extended operating system functions* accessible to the appropriate applications (and, in the case of, say, desk top video conferences, to actors directly). If they are not conceived of *and implemented* as general system functions that can be accessed from and combined with applications, the delicate and dynamic relationship between cooperative and individual work breaks down. This applies to single-user as well as multi-user applications.

While it is unlikely that the infinitely rich variety of modes of interaction in the articulation of cooperative work can be replicated in CSCW systems, the above analysis of modes of interaction indicates that certain facilities are required of CSCW systems for actors to be able to articulate their distributed activities in relation to computer systems in a sufficiently fluid way.

First, it seems necessary for actors to be able to control the articulation of their cooperative activities in terms of parameters such as different kinds and degrees of *obtrusiveness* and different kinds and degrees of *persistence*.

The control of articulation work in terms of such parameters might be conceived of in the same way as access control (in shared object servers) and floor control (in shared view systems). That is, the different policies of obtrusiveness should be user-selectable (Rodden and Blair, 1991). In addition, since it is unlikely that a finite set of policies can be identified, the policy ‘control panels’ should be open to respecification and addition — in much the same way as suggested by Greenberg with respect to turntaking protocols (Greenberg, 1991).

Second, since embedding cues in artifacts that are part of the field of work — and hence artifacts that are ready-at-hand, perhaps ubiquitous, and constantly monitored — plays a crucial role in the articulation of cooperative activities, actors should, in principle, be able to highlight any object in the computer environment in multiple ways, with different degrees of obtrusiveness and persistence. Again, this implies that actors should be able to control the way in which an object is highlighted, how the highlighting is propagated within the cooperative ensemble, who has access to changing the status of the highlighting, and so on. Since facilities that could meet these requirement will encroach upon what has heretofore been thought of as single-user applications, such facilities will have radical implications for the design of a CSCW operating system.

(3) Third, a vast — presumably open-ended — array of interactional activities is involved in the articulation of cooperative work. Different modes of interaction are combined and meshed dynamically, according to the requirements of the specific situation at hand, and are meshed fluently and, more often that not, effortlessly. A CSCW system should support the fluent interweaving and combination of modes of interaction.

In sum, in order to meet these very general requirements — support the fluent meshing of individual and cooperative activities as well as the multitude of modes of interaction — the allocation of function between general operating system facilities and specific applications should be planned and designed carefully.

5.2. Requirements for incorporating computational mechanisms of interaction in CSCW applications

Since mechanisms of interaction are enmeshed in the semantics of the particular work domains, a computational mechanism of interaction should be conceived of as an abstract device incorporated in a software application (e.g., a CASE tool, an office information system, a CAD system, a production control system, etc.) so as to support the articulation of the distributed activities of multiple actors with respect to that application.

The purpose of the concept of mechanisms of interaction is thus to facilitate the design of domain-specific software applications in such a way that they incorporate the mechanisms of interaction as devices that support the articulation of distributed cooperative activities with respect to these applications — without imposing on actors an undue impedance between articulation work and work.

Now, cooperative work is articulated along multiple dimensions: who, what, where, when, how, etc.? These dimensions of articulation work are interdependent and these different aspects of articulation are thus themselves to be meshed in a fluent way. Since mechanisms of interaction are local and temporary closures, no mechanism of interaction has global validity. Hence, in order not to impose artificial distinctions and thereby disrupt the ongoing articulation work, facilities should be provided that support the linking of different mechanisms (Malone et al., 1992). Mechanisms of interaction should therefore be conceived of as abstract devices that support the fluid interrelation of articulation work with respect to the *multiple applications* required to do the work in a particular setting. For instance, in the case of mechanical design, project management tools, CAD tools, process planning systems, classification schemes for common repositories (of components, work in progress, drawings, patents), and so on.

5.3. General requirements for computational mechanisms of interaction

From the evidence of the corpus of empirical studies of uses of artifactually embodied protocols for articulating cooperative activities, we have derived a set of general requirements for computational mechanisms of interaction and, by implication, for a general notation for constructing computational mechanisms of interaction.

First and foremost, since mechanisms of interaction, as plans in general, are “resources for situated action” (Suchman, 1987), a mechanism of interaction must be *malleable* in the sense that it supports users in specifying its behavior.

(1) Global and lasting changes. Since organizational demands and constraints change, it should be possible for actor to design and develop new mechanisms of interaction and to make lasting modification to existing ones. In the case of the bug form mechanism, for example, the entire mechanism — the artifact as well as the procedures and conventions — was designed from scratch by the actors themselves. Accordingly:

> A computational mechanism of interaction must provide facilities for actors to specify and respecify the behavior of the mechanism so as to enable actors to meet changing organizational requirements.

(2) Local and temporary changes. Actors must be able to make local and temporary changes to the behavior of the mechanism, for instance by suspending or overruling a step, by ‘rewinding’ a procedure, escaping from a situation, or even restarting the mechanism from another point. That is:

> A computational mechanism of interaction must give actors control of the execution of the mechanism so as to cope with unforeseen contingencies.

In making such specifications, actors may not be able to completely specify the behavior of the mechanism or they may prefer not to specify certain attributes explicitly or to defer their specification:

(3) Partial definitions. While a mechanism of interaction cannot be constructed without explicit conventions and prescribed procedures, mechanisms of interaction are, in principle, under-specified (Suchman, 1983; Suchman and Wynn, 1984; Suchman, 1987). Protocols are, to some extent, only specified in the course of the work. Furthermore, a protocol and the whole equipage of ensuing stipulations can be invoked implicitly, without any explicit announcements, for instance by certain actors taking certain actions (Strauss, 1985; Schäl, 1994).

Thus, in order to allow for implicit understanding of certain aspects of articulation work as well as incomplete and not-yet complete specification, and also in order not to force actors to explicitly specify a mechanism of interaction to a larger degree than deemed necessary, the mechanism should provide means for handling *partial specifications of attributes*. That is, it should be possible for attributes to be left un-specified and for the missing specification to be provided, perhaps at a later stage, by another mechanism or by inference from actions taken by actors. For example, if actor A starts performing task *a*, he or she may then be taken to be committed to accomplish task *a* and it may also be inferred that he or she has assumed the role *x* defined as responsible for task *a*. Hence,

> A computational mechanism of interaction must provide avenues for attributes to be left un-specified and for the missing specification to be provided, at some point, by another mechanism or by inference from actions taken by actors.

(4) Visibility. From these requirements (1-3) follows that the specification of the behavior of the mechanism must be 'visible' to actors, not only in the sense that it is accessible but also, and especially, that it *makes sense* to actors as specifications in terms of articulation work:

> In order for actors to be able to exercise their control of the execution of the mechanism and respecify the behavior of the mechanism, the specification of the behavior of the mechanism must be accessible and manipulable to actors and, more specifically, accessible and manipulable *at the semantic level of articulation work*.

Since the specification of the behavior of the mechanism must be 'visible' to actors *at the semantic level of articulation work*, the objects and functional primitives offered by the mechanism must be expressed in terms of operations of articulation work with respect to roles, actors, tasks, activities, conceptual structures, resources, and so on (cf. the model of articulation work in Figure 15).

(5) Control of propagation of changes. Since articulation work is a recursive function (Gerson and Star, 1986), changing a mechanism of interaction may be done cooperatively, as part and parcel of the cooperative effort. That is, it should be possible to change the mechanism of interaction while it is running, without having to suspend all activities within the cooperative ensemble for some time:

> A computational mechanism of interaction must provide means for dynamic reconfiguration of the protocol and, accordingly, give actors means of controlling the propagation of changes to the specification of the behavior of the mechanism.

(6) Relating to the field of work. Since mechanisms of interaction are 'local and temporary closures' (Gerson and Star, 1986), no single mechanism will apply to all aspects of articulation work in all domains of work. Accordingly, a computational mechanism of interaction is to be conceived of as a specialized software device that is distinct from the state of the field of work and yet embedded in an application so as to support the articulation of the distributed activities of multiple actors with respect to the field of work as represented by that application.

> As an embedded system, a computational mechanism of interaction must provide means of identifying pertinent features of the field of work as represented by the data structures and the functionality of the application in which it is embedded.

(7) Linkability. Since no single mechanism will apply to all aspects of articulation work in all domains of work, the computational mechanism of interaction must provide means for establishing links with other computational mechanisms of interaction embedded in other applications:

> A computational mechanism of interaction must provide facilities for establishing links to other mechanisms of interaction in the wider organizational field.

5.4. Objects and functions of articulation work

A crucial element of a general notation for constructing computational mechanisms of interaction is the underlying, general model of articulation work.

According to Strauss, cooperative work is articulated with respect to multiple "salient dimensions", that is, with respect to dimensions such as: who, what, where, when, how, etc. (Strauss, 1985). Taking this observation further, we (tentatively) suggest the following objects as the 'elemental objects' of a model of articulation work that can provide a conceptual foundation for constructing computational mechanisms of interaction:

On one hand, the distributed activities of a cooperative work arrangement are articulated with respect to objects pertaining to *the cooperative work arrangement* itself, that is:

- Articulation in terms of **roles**, that is, in terms of general responsibilities for classes of tasks and resources.
- Articulation in terms of **actors**, that is, the committed or actual participants in the cooperative effort in question (in different capacities such as roles, jobs, individuals, collectives): Who is committed to do what when? Who is doing this?
- Articulation in terms of **human resources**, that is the potential participants in the cooperative effort in question: Which partners are potentially relevant for a particular project in terms of skills, competing commitments etc.? Who are available when?

- Articulation in terms of **tasks**, that is, in terms of an operational intention (goals to attain, obligations and commitments to meet): What is the problem? What is to be done? Who should do it? Should I do it? Which task is (normally, advisably, or according to statute) to be undertaken in which circumstances, by which actor, based on what information and which criteria, creating what information? What is the (normal, advisable, or statutory) relation between different tasks (procedure, workflow)?
- Articulation in terms of **activities**, that is, in terms of an unfolding course of purposive action. What are the others doing, and why? What have they done, what will they be doing, etc.? Do they cope?[32]

On the other hand, the distributed activities of a cooperative work arrangement are articulated with respect to objects pertaining to *the field of work* of that cooperative work arrangement:

- Articulation in terms of the common **resources** which constitute the field of work, potentially or actually:
    - ◊ **information** resources (documents, letters, applications, notes, files, memos, reports, drawings): Which actor can access, change, delete, copy which information resources? To which actor is the object to be displayed, in which format? Which actor can see who doing what to which objects?
    - ◊ **material** resources (materials, components, assemblies). Which materials, components, assemblies are available where, when, how, in which quantity? What are their characteristics?
    - ◊ **technical** resources (tools, fixtures, machinery, software applications). What are their operational characteristics (machining tolerance, suitability for different kinds of materials and material dimensions, processing time and cost)?
    - ◊ **infrastructural** resources (rooms, buildings, communication facilities, transportation facilities). What are their operational characteristics (capacity, location, compatibility, turnaround time, bandwith)?
- Articulation in terms of **conceptual structures**, that is, in terms of the relationship between categories used within a specific community as ordering devices with respect to the field of work, either by *adopting* conceptual structures (by defining categories, i.e. by establishing prototypical, causal, genetic, historical, means/end relationships between categories), or by *applying* such conceptual structures (by classifying events, objects, etc.) so as

32 The terminology used here comes from the Scandinavian tradition within software development: An *activity* is used to denote a work process as an unfolding course of action, but only those aspects of a work process that are relevant to doing the work with the currently available resources, not all other incidents that may occur in the same course of action but which are of no consequence for getting the work done (like spilling coffee). — The concept of a task, on the other hand, is used to denote an operational intent, irrespective of how it is implemented. A task is expressed in terms of *what*, an activity in terms of *how*. A task can be *accomplished*, an activity can cease. (Andersen et al., 1990)

to monitor activities with respect to, direct attention to, make sense of, act on etc. certain aspects of the state of the field of work.

As indicated, these dimensions of articulation work are interdependent. For example, articulation with respect to *tasks* may refer to a set of activities realizing a particular task, the actual actor doing the activity, various resources deployed to the activity, the categorization of the resources pertaining to the field of work.

However, in order to be able to grasp the dynamics of articulation work, we need to make another distinction, namely between *nominal* and *actual* articulation work, that is, articulation work in term of *nominal* (ideational, potential, not yet realized) or *actual* (existent, definite, realized) objects and operations.

That is, the model of 'objects' of articulation work and the concomitant 'operations' can be ordered along two axes, as in Figure 15:

(1) On the one hand we distinguish articulation work according to its status, that is, *nominal* and *actual*.

(2) On the other hand we distinguish articulation work with respect to the component parts of the *cooperative work arrangement* and the objects and processes of *the field of work*.

Nominal		Actual	
Objects of articulation work	**Operations with respect to objects of articulation work**	**Objects of articulation work**	**Operations with respect to objects of articulation work**
Articulation work with respect to the cooperative work arrangement			
Role	assign to [Committed actor]; responsible for [Task, Resource]	Committed-actor	assume , accept, reject [Role]; initiate [Activity];
Task	point out, express; divide, relate; allocate, volunteer; accept, reject; order, countermand; accomplish, assess; approve, disapprove; realized by [Activity]	Activity	[Committed actor] initiate; [Actor-in-action] undertake, do, accomplish; realize [Task]; [Actor-in-action] makes publicly perceptible, monitors, is aware of, explains, questions;
Human resource	locate, allocate, reserve;	Actor-in-action	initiates [Activity]; does [Activity];
Articulation work with respect to the field of work			
Conceptual structures	categorize: define, relate, exemplify relations between categories pertaining to [Field of Work];	State of field of work	classify aspect of [State of field of work]; monitor, direct attention to, make sense of, act on aspect of [State of field of work];
Informational resource	locate, obtain access to, block access to;	Informational resources-in-use	show, hide content of; publicize, conceal existence of;
Material resource	locate, procure; allocate, reserve to [Task];	Material resources-in-use	deploy, consume; transform;
Technical resource	locate, procure; allocate, reserve to [Task];	Technical resources-in-use	deploy; use;
Infrastructural resource	reserve;	Infrastructural resources-in-use	use;

Figure 15. The table identifies the elemental objects of articulation work and gives examples typical elemental operations on these objects.

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Mechanisms of interaction and technologies of representation: Examining a case study

James Pycock

Manchester University

1. Introduction

The paper[33] begins with an overview of the some of the organisational details of a field study that has been reported in chapter 2.6. In that paper a more ethnographic perspective on the case was taken and particular attention was paid to the practices involved in making sense of the mechanisms of interaction which were at play in the work observed.

In this document I want to use basically the *same* case details but to use them to try to introduce some concepts from a literature on ‘technologies of representation’ as a basis for the analysis and for informing the developing concept of ‘Mechanism of Interaction’. I shall reference a number of sources for this literature within the text including Latour (1983, 1988), Law (1986), Cooper (1992) and Bowers (1992a, 1992b). I begin with a reminder of the basic details of the case study.

2. The field study details

The field study concerned a project designing and developing the hardware and software for photocopying and printing equipment. When this field work was conducted, the project studied was in the midst of testing a fleet of prototype machines and attempting to achieve the stabilisation of the mechanical and software configurations of these machines, so that the project could enter a next phase.

2.1. The Testing

The testing involved a number of the prototype machines being used to do photocopying and being run pretty continuously through the working day, at one stage even on Saturdays. The machines were operated by some (usually) casual employees, who were required to run a variety of printing jobs on the machine.

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2.1.1. The Test Matrix and the cycle of print jobs

Something called the test matrix told these employees what types of photocopying jobs were to be performed with the prototype machines. That is they were required to operate the machines according to a sequence in which the kind of print job to be run, the size type and quality of paper (transparencies, labels etc.) to be used, the number of copies to be printed, and so forth, would be varied. There were also different test zones were the operating humidity and temperature conditions were varied. The details of each job were provided in a manual and the operator would work through a cycle of them, and then operate the cycle over again.

2.1.2. The Test Rules and responses to faults

In doing these copying runs the machines would occasionally breakdown. When this occurred operators had to follow a set of test rules governing their responses to the faults. They were permitted to respond to certain faults by, for example, clearing a paper jam themselves and restarting the machine, but with other faults they were required to call in the company repair staff - ‘tech reps’ - who would come in and would correct the fault. The operators were also required to follow the standard rules for clearing paper jams, because, of course, the machine provides specifications of the way in which paper jams can be fixed, but, if those correctives fail, then the test operators are prohibited from taking further measures, even though they might be able to fix the fault themselves without calling in the repair staff.

2.2. The Reporting

2.2.1. Fault Report Forms

Malfunctions that occurred during printing operations and the measures taken to correct the faults were recorded by test operators by completing what was known as ‘Fault Report Forms’ (FRFs). Likewise, if ‘tech reps’ were called out they would record the nature of the fault they had found and the measures taken to correct it. These were known as ‘unscheduled maintenance’ calls (or ‘UMs’). FRFs contain extensive detail of the malfunction, involving a number of standardised categories of information (machine number, operator etc.) and space for (relatively) discursive descriptions of the malfunction (see chapter 2.6 for diagram). The FRF records the time at which the fault occurred, the number of sheets printed since the last fault, the number of faults recorded for this machine, the conditions of temperature and humidity under which it was operating, and the nature of the fault and of corrective action taken. The Fault Report Forms are numbered and there are also standard fault codes (e.g. 4455 or 6088).

2.2.2. The Daily Report

A Daily Report of the testing activities was produced for the project as a structured paper artifact. This provided a summary of the FRFs with the Fault Report Form number listed alongside a (typically) abbreviated statement of the fault.

2.2.3. Performance criteria

Additionally the project was concerned with the performance of the machine upon certain criteria. The criteria included the number of the breakdowns and hence FRFs and UM's (with a target of no more than 6 UMs per million sheets). A second criteria was the length of time a machine was 'on-test', as opposed to 'off-test'. A machine was 'off-test' for the time taken for repair staff to arrive and diagnose a fault and provide a solution or to modify or replace parts. The aim is to have the machine 'on-test' for as much time as possible, with as few faults as possible and, furthermore, for it to meet a target of the number of pages fed through and printed.

A number of other criteria (such as the number of sheets printed per print cartridge) were in operation but the point is that the ultimate project aim was to get the machine's performance up to a certain consistent level at which it can be operated without modification of parts or software.

Details of performance levels were produced for the project as a collection of separate sheets each of which provided a cumulative record for a particular prototype machine and a display was kept of the number of sheets fed through the machine, the number of UMs, the time 'on test', the number of days in a particular test chamber with specific humidity and temperature conditions, and so on.

The production of the Daily Report for the project was part of the specialised job done by the project's data analyst.

2.3. Sunrise Meeting

The 'Daily Report' was read out in the course of what was called the 'Sunrise Meeting' for which it was the main focus of business. The meetings started at 8.30am, lasting for one hour and occurred each morning of the working week. As we have said the project had entered a testing phase and it was the business of the 'Sunrise Meeting', at the time of recording its affairs, to be dealing with test operations. One of the primary tasks of the sunrise meeting was, therefore, to deal on a day to day basis with the faults reported in test. The participants in the sunrise meeting were distributed with print outs which summarised the number of fault report forms for each machine and the general nature of the fault reported. The project's data analyst was in possession of full copies of the FRFs and it is the data analyst who played a central role in the meeting by reading through the full fault report forms.

So the meeting reviewed the contents of the 'Daily Report' by considering the fault reports for each machine in turn, the order of review being governed by the machines' age. The progression through these forms on a machine-by-machine basis resulted from a concern to track the history of the specific machines. The data analyst reads out the machine number, the FRF number, the repairer's statement of the fault and of the measures taken to deal with it.

As reported earlier the data analyst brings along the original fault report forms and, occasionally, materials that accompany the report. Thus, if the fault involves unevenness in the distribution of toner on the paper, errors in text printing, staining of paper or the breakage of some small piece of hardware (such as a screw) then a sample sheet of paper or the broken pieces of metal will be attached to the original FRF. The sample may be handed over for close inspection by one or more participants at the Sunrise meeting.

2.3.1. From faults to problems

The members of the Sunrise Meeting attempted to understand the individual faults reported in each of the FRF's to determine and classify, for example, which part of the machine produced the fault, whether a long catalogue of individual faults arose from a single problem, whether the faults were ones they had seen before or a variant or were something new, whether the faults reflected on the design of the copier or if they were routine and would be expected even in a production version of the machine, whether a pattern was emerging, and so on. In this way there was no one-to-one link between reported faults and problems to be solved by the project but it was one of the tasks of the Sunrise meeting to read the FRF's for new and significant design problems.

Additionally there were different significances for the project of what were decided to be problems. That is those faults or series of faults that the meeting decided were problems, and were new problems, were then categorized into either 'critical' problems threatening the life of the project, or 'major' problems which would effect the quality, the cost and the delivery aspects of a manufactured product or 'ordinary' problems which given time and effort could straightforwardly be solved by the project.

2.3.2. Problem totals and the project's 'to do' list

In this way problems were considered from the point of view of their meaning for the progress of the project and so it was of concern, for example, whether the faults were the sorts of faults that the project should now be encountering at this stage in the testing work or ones they thought they had seen the back of?, what kind of time scale might there be to a fault?, and could its fixing delay other things?, was there any pattern to any of them?

The project was, in various ways, falling behind, and so it was an omnirelevant concern as to what any particular problem might mean with respect to progress. There were 'state-of-the-project' displays of the problem totals. The displays concerned such questions as: how many, if any, critical problems did the project have?, how many major?, and how many ordinary?. There was also the ratio between problems found and problems fixed which was monitored closely. The problems constituted tasks for the project - that is problem solving tasks - and progress on the project was via problem solving and displays of problem totals constituted the project's 'to do' list.

2.3.3. Project Schedules

There were various other measures of performance and progress for the project as a whole and summary data about the current rate of unscheduled maintenances, the time 'off-test', the total sheets run through, and the like, was one of the first things to be checked about the machines as the meeting considered how any day's performance related to overall performance. In fact the project meetings routinely *began* with displays of project progress. These involved, particularly, the display of the project schedule. The project schedules were displayed in order to show how work was going relative to the targets that the schedule had set for it, and, of course, to look for potential signs of slippage from them.

2.3.4. Problem origins and distributions

The project also monitored the distribution of problems. That is, given that there were different origins of the malfunction in the machine, then there could be a spread of problem locations, with some parts of the machine (such as the software) responsible for many faults while others seemed to be functioning perfectly. Some parts of the design and development caused a lot more problems than others. That is, there were different numbers of problem solving tasks associated with different parts of the machine and its design.

2.3.5. From Problems to Tasks

The problem solving tasks were allocated to different specialist engineering groups, or modules, within the project team by making modules responsible for machine parts. That is, these groupings known as 'modules' into which the different specialists were subdivided were characteristically identified by the name of the part or function of the machine for whose design the module teams are specifically responsible, such as the 'stacker' group, and the 'fuser' groups. Part of the business of the 'Sunrise Meeting' was to confirm allocations of problems to modules, and attendance of the leader or representative from each of the subgroups was therefore required to ensure that someone was present to speak on behalf of the module and to the problems which might potentially be allocated to it.

2.3.6. Engineer's to do lists

The Sunrise meeting reviewed the FRFs for problems that had to be added to the total of project tasks - its 'to do' list. The meeting also allocated those tasks to module groups responsible for the machine part which caused the problem. Engineers on the project had to solve the problems and engineers' 'to do' lists enumerated problems which they were meant to be clearing. Just as with the project's total list of problems, so the engineers 'to do' list could have new tasks added, old ones cleared and the ratio between new additions and successful clearances could vary at different times. At some points engineers fully expected that problems would be being added faster than existing ones were being cleared, and they saw this as normal in certain phases of the project.

2.3.7. Reading the details

A few other points before moving on. The Sunrise meeting also sometimes discussed whether an FRF provided adequate and sufficient relevant detail about a fault and the actions taken to correct it, such that the meeting could interpret it and decide whether it was a real or serious problem. That is the meeting sometimes had to decide if it could in fact decide or if it required more information.

2.3.8. Changing the testing

Secondly, the meeting also on occasions made changes to the testing operations. One particular change concerned 'waivers' which were essentially mechanisms by which certain problems were ignored for the time being so that the project could progress and move towards exiting the phase it was presently in. So, for example, the Sunrise Meeting could put a waiver on all problems resulting from using labels in the machines and test operators would not have to report these faults on FRFs.

2.4. Summary

As might be expected there are many more details of the organisation of the work in this case which could be given and the above is only a brief and basic overview. Before moving on a quick summary.

The project was in a test phase. It used a matrix of jobs to test prototypes from which faults occurred. The responses of operators to these faults were governed by test rules and the details of faults and corrective actions were recorded on the FRFs. The FRFs and performance levels on a number of criteria were summarized in a 'Daily Report' and a daily meeting known as the 'Sunrise Meeting' decided, on the basis of this information, if the faults were problems, how serious they were and allocated them to engineering modules to solve them. The meeting could also change the test rules and the matrix and considered the overall project progress and performance against its schedule. Engineers ended up with a set of problem solving tasks to complete.

3. Introducing Concepts from Technologies of Representation

Let us go over this case again to introduce some concepts for analysis from the literature on Technologies of Representation, and here I am thinking of the work of John Law, Bruno Latour, Bob Cooper and John Bowers. These concepts have been drawn upon by, for example, Suchman and Trigg (1992) but *perhaps* remain underplayed in CSCW in general and may specifically contribute to our understanding of aspects of MOIs.

3.1. Pasteur and Photocopier Testing

Let us start with the testing operations aspect of the photocopier project. Are there any cases within the Technologies of Representation literature that might inform our analysis of the testing operations? Well, perhaps surprisingly, one such case might be Latour's (1988) report of Louis Pasteur's development of an antidote to the Anthrax bacillus!

3.1.1. Developing the Anthrax antidote

To be brief a number of aspects of this historical case study can be highlighted:

(1) Firstly, an invisible microbe was decimating populations of cattle on the farms in France.
(2) The disease was variable and unpredictable making it difficult to study.
(3) Work had to be done to make it amenable to laboratory investigation.
(4) Pasteur had to travel to the outside world of the French countryside and return to his laboratory in Paris with the specimens containing the microbe.
(5) In the laboratory he was able to grow the bacillus in isolation and in large quantities making it 'visible' and visible apart from the other organisms mixed in with the original sample.
(6) He was able to simulate anthrax outbreaks.
(7) He manipulated the conditions of the simulation.
(8) He charted and recorded the features of the outbreaks and the disease in these varied simulations.
(9) He was able to isolate the cause of death of his test animals and directly attribute it to the microbes.
(10) He was able to provide an antidote for the disease.
(11) After developing the antidote he organized a field trial on a larger scale to demonstrate its effectiveness and reproduced some of the features of his laboratory work in the countryside.

(12) Finally, farmers and vets were able to use Pasteur's techniques themselves.

3.1.2. Comparisons with photocopier testing

We can make a number of comparisons with the testing in the photocopier case as a starting point for introducing a number of concepts. There are by no means perfect parallels between these cases but it might be more than just playful to compare them. (Some of the divergence between the cases comes from a difference between a reactive and a pro-active approach which I will indicate):

(1) Firstly, faults with photocopiers decimate work in offices, certainly in my department anyway.

(2) These faults are distributed across the photocopier world at remote sites. They occur occasionally, unpredictably and are variable in nature. (Because they result from complex interactions of multiple parts, different conditions of use and environments in which the copiers are situated).

(3) Work needs to be done to make this distribution of faults suitable for 'laboratory' investigation. (Here is the reversal of the reactive/pro-active approaches. With Pasteur he was reacting to outbreaks of microbes in the countryside, while with photocopier design the engineers are trying to pro-actively avoid such outbreaks with their new design that will go out into the 'field').

(4) The outside world is brought into the testing lab in the form of the test matrix and the test rules. To expand:

The test *matrix* represents the diversity of conditions and range of tasks that a machine might in 'real life' be used for - that is for printing transparencies and labels, for example, with different qualities of paper, and under different conditions of humidity and temperature which can critically effect performance. The test matrix represents certain relevant aspects of photocopier usage in the outside world (and by relevant I mean that the colour of the office wall paper is not represented in the matrix as a crucial variable in the situation of photocopier use).

The test *rules* are also designed to bring in aspects of the 'outside world' by representing the types of 'reasonable' courses of actions a 'normal user' in the outside world might take. That is users are assumed to be people who, for example, will, upon having cleared a paper jam press the restart button, and who, if this results in failure to restart the machine, might press the 'reboot' button and if this results in failure may call out the company repair staff. These are conceived as reasonable responses to the fault situation encountered, and as ones which must, therefore, be accommodated in the conception of the machine's ordinary operations in the real world and are to be represented as rules to govern the response to faults that occur with the prototype machine in test.

That is the 'user' is seen as someone who is assumed to be using the machine on the basis of cursory inspection with only a minimal knowledge of the machine, someone who had no more than a routine grasp upon its operations, and certainly not someone who had long standing, detailed and intricate familiarity with the machine's ways and who could devise their own resolutions of faults that might become manifest. This is of course in contrast to the test operators who have worked for a long time and closely with machines under test and could take advantage of their familiarity with the faults of the machines and use their accumulated knowledge of what will get the machine operating again without having to call out repair staff. The point of the test is not to find ad hoc ways of solving the machine's problems, but for the project to find ways of reducing those (design) faults which will occasion the routine user in the outside world to call a maintenance engineer and to that extent they want the test operators inside the test lab to simulate the conduct of those users who will not be able to get the machine working again by means of the specified procedures and who will therefore call for the engineer. These experienced test operators were therefore to be prevented from making use of their familiarity in dealing with any problems that the machine might present by making their responses to faults rule governed in order to simulate 'normal use' typically by persons who have no comparably sustained familiarity with the machines and their ways.

The test rules also took account of the standard procedures for clearing paper jams and the like, because, of course, machines themselves in the outside world provide specifications of the way in which paper jams can be fixed.

(5) So returning to our comparison with Pasteur. In the test chambers the fault 'microbes' (or should we say 'bugs') need to be grown by the photocopier design project. That is the test operations are aimed at *producing* faults, not out there but in here, within the project, within the development site. They are grown 'in large quantities' by concentrating the faults into a small time scale and localised at one site by continuously feeding the machine huge quantities of paper as quickly as possible (sometimes even on Saturdays).

The *concentrated* use of the photocopiers makes their faults 'visible' and visible apart from the photocopiers' otherwise correct functioning. That is, faults are mixed in with smooth functioning and in the outside world, with normal levels of usage, the faults do not occur with a level of concentration that makes them particularly suitable to laboratory investigation - with the temporal and other constraints that laboratory work involves. The faults arising from intensive use are also *recorded* in the FRF's so that they remain 'visible'.

(6) As we have seen fault outbreaks are simulated by organising testing activities around the test matrix and the test rules. The test matrix representation specifying the simulation of the diversity of conditions and the range of tasks that a machine might 'in real life' be used for, and the representation of normal users and their responses contained in the test rules specifying the simulation by constraining the activities of those test operators and organizing them with respect to the outside users' lack of familiarity.

(7) The conditions of the simulation are manipulated by these representations of the external world of photocopier use and also by decisions made at the Sunrise meeting to change the testing operations, for example by running more of a certain quality of paper on a certain machine in a certain humidity zone, perhaps with

the intention of reproducing particular faults or achieving significant occurrence rates for a fault type.

(8) The features of the breakdowns and the fault symptoms in these varied simulations are recorded in detail on the FRF. They are charted by going over them, or a series of them, in discussions in the Sunrise meeting, and by charting the number, significance, source and distribution of project problems on various displays.

(9) As well the FRF descriptions of a fault and any associated evidence (such as a broken screw) fault causes may be also isolated and identified with the help of the information which is recorded about the conditions of usage which the machine was experiencing when the fault occurred. Additionally, the task of isolating causes of malfunctions is assisted by the detail regulation and recording of the actions done to the machine in response to a fault (or the series of actions performed in cases where a series of faults occurred).

(10) The engineers and the project solves its problems - problem by problem.

(11) After developing solutions to the design problems, a field trial on a larger scale can be organised to demonstrate the photocopiers' effectiveness, we might call this beta testing. (This is also, of course, partly a procedure for increasing the production of some of the rarer faults; but a procedure that only becomes practical when the more common faults have been solved).

(12) Finally, when new photocopiers are produced and sent out into the world they may have attached to them a package in which knowledge about faults and techniques for getting rid of them are represented (in a portable form) as text, diagrams, flow charts and the like. These may also in some cases simulate and reproduce certain features of the laboratory and its working procedures. For example, step by step procedures, rules or tables for fault diagnosis are often seen reproduced in user manuals that accompany machines. We might also speculate that as well as users - our equivalent of Pasteur's farmers -that photocopier engineers - our equivalent of the vets - might too be provided with more detailed and specialist techniques, information, advice on problem solving and fixing photocopier malfunctions based upon the work of the project conducted within the development site.

Clearly these two stories - one of vaccine discovery, the other of photocopier design - are not identical. However there are some communalities (in procedures and the roles of representations) and perhaps such an initial comparison will let us bring in useful concepts for analysis from this literature on technologies of representation in order to understand our contemporary case of photocopier design and inform the core notion of mechanism of interaction.

3.2. The Test Matrix and Rules - some roles for representations

3.2.1. Boundaries

The cases we have discussed above are full of talk of the *outside* world - the farms of France or photocopiers in offices spread across the world - and on the other hand the *inside* world - Pasteur's lab in Paris or the design project's test chambers. However we can also see the role of representations in bringing the outside world inside - in the form of the simulations specified by the test matrix and the test rules - and the role of representations in sending the inside world out - in the form of procedures for removing paper jams or perhaps even solutions to software problems that are represented and reproduced in code distributed within each new machine. These movements between the outside and the inside, and visa versa, challenge the normal notions of boundaries. The technologies of representation approach suggests that we question an idea of a static, fixed distinction between the outside and the inside of an organisation and see them less as separate places than as correlative structures in which there is "complicity mixed with antagonism" (Cooper 1992 quoting Starobinski 1975), in which the outside needs the "inside fending it off, resisting it". Such literature suggests a relationship in which the outside and inside can *reverse* into each other or one can be *folded* into the other by means of representations which re-present the outside inside or the inside outside, the periphery at the centre or the centre at the periphery. This is also a transformation of scale by the use of representation. The large-scale outside is made manageable and small-scale inside, but then reversed to make the small insides distributed on a wider scale.

3.2.2. Making material visible

These transformations also involve the making of intransigent material into a form that is manageable, can be handled and is visible within, in this case, the development site. That is the *concentrated* use of the photocopiers makes their faults 'visible' and visible apart from the photocopiers' otherwise correct functioning. These visible faults are, furthermore, *recorded* in the FRF's so that they remain 'visible'. (However we should note that what is visible and to whom and at what time is carefully managed. For example, while the outside is brought inside and the faults made concentrated and visible, the work of the insides - mistakes made in the development process, problems not properly solved, and so on - these are kept private within the boundaries of the development site, that is at least until a set release date).

3.3. The Fault Report Form - some features of representations

Let us now consider a second stage in this testing of the photocopiers and introduce some further concepts for our analysis. We saw in the first stage how the test matrix and test rules specified the test operations (based upon representations of the outside normal use and users) and brought the faults into the laboratory, into the development site, into the project and made them visible *there*. A second stage - the stage of recording the details of the faults on fault report forms - which we shall now consider, involves using representations to turn faults into forms. There are a number of advantages in representing faults in terms of fault report forms which are worth considering.

As described the faults of photocopiers, distributed in space and time around the world, are brought into the test chambers where they can be simulated in one place and during set times of the projects life, however, within the project itself and for the local organisation of the work, the faults being produced in the test chambers *still* occur at all times of the working day (sometimes on Saturdays) and across the whole fleet of photocopier machines. This is in contrast to the Sunrise meeting which starts at 8.30am on each weekday morning - same place, same time and yet has access to all the previous days faults. It is the representation of the faults as FRFs which offers the advantage of allowing the project to bring the faults to the one place and to the one time of the Sunrise meeting. According to the technologies of representation approach it is the FRF representation which means that project experts and module leaders do not have to wait around the test zones for faults to happen or have to *constantly interrupt* their work to go and see faults that have occurred, that engineers do not need to be in two places at once if faults occur at similar times but on different machines, that a machine can be repaired and got back ‘on-test’ as soon as possible and ready to produce more faults without the concentration going down as it would if the testing had to wait for project experts to come to the machine, to see the fault, to decide about its seriousness, to allocate it to a module and so on; nor do experts have to witness a series of faults in real-time to view them sequentially. The list of advantages of forms over faults goes on.

3.3.1. Attributes

According to the technologies of representation literature these advantages stem from a number of features that representations such as Fault Report Forms have. In our work on mechanisms of interaction we may be able to usefully drawn on some of these notions:

Mobility

Firstly representations are mobile. The FRFs are portable and can be moved from the testing chambers where operators and tech reps fill them out, to the data analyst who collates them and summarizes them into a Daily Report and who moves this report and the original FRFs to the room of the Sunrise meeting at 8.30am each morning, so that the faults reported are re-presented to the module leaders. In this way the FRF also moves between a number of different 'user groups' - test operators, company repair staff, data analysts, module leaders and so on.

This is said to be because representation is always a substitution for, or re-presentation of, the event/phenomena and never the event/phenomena itself. For example, representations of mountains in the form of maps are not the mountains themselves and it is the map which we move with us. Similarly the project did not wheel photocopiers jammed with bits of paper around the development site for experts to examine, it simply sent forms to the data analyst. The events and objects of the world are re-presented somewhere remotely from their origin, representations of events and objects allow them to be 'taken' or to be seen somewhere distant, somewhere where it may be more convenient to consider them, somewhere where other representations are being brought and also collated, somewhere near to you. However, though remote events are brought near they are at the same time kept at a remove through the intervention of representations[34]. The substitution of symbolic artifacts, maps, models, numbers, formulae, reports and so on for direct and immediate phenomena in the field of work (FOW) and the independence of these representations from the FOW and its constraints is said to provide a distance and an abstraction but also a means to span that distance.

Action at a distance or remote control

It is also said that if representations of events (such as photocopier faults) are transported to somewhere distant away from the original source of the events (to somewhere like the Sunrise Meeting) and at this distant location the representations are manipulated and then some version of them is made to travel back to the source of the events (such as the test chambers) then technologies of representation can be viewed as a basis for action at a distance and influence over remote activities - that is activities remote from where representations are manipulated. (John Law (1986) for example, describes some of the representations used in the 15th century which he believes underpinned the 'long distance' influence that the Portuguese had over the East Indies. He describes the use of representations such as navigational charts and sail design technologies).

Some of the literature in the technologies of representation approach describes these ideas of action and influence at a distance as 'remote control', where control is linked to notions of 'power' and 'domination'. Work within Strand 2 and 3 of COMIC (see for example chapter 2.6 and Deliverable 2.1 page 208) and within CSCW (e.g. Suchman 1987) has expressed a number of reservations about con-

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34 In some ways this argument is similar to a number of the criticisms that some Participatory Design approaches make of Task Analysis in HCI. That is in task analytic approaches the user is taken into account in the designing of the computer system, but their needs, in the form of their task requirements, are brought into the design process by means of representations in the form of task models. Participatory design workers suggest that while this brings the users near to design it also keeps them at a remove, that the task models and the task modellers unnecessarily sit between the users and the designers such that users are denied direct contact with the design process.

ceiving of this relationship between action and representation as one of execution. This work - which focuses on the situated nature of action, the use of representations as resources and the variability of the pre-determination of courses of action - is well known within CSCW and COMIC. Additionally work within COMIC (for example MAN-1-5) has challenged notions of technological (and organisational) determinism. Consequently, in this paper I do not want to repeat these debates about the status of representations, their relationship to action, the role of technologies in changing working practice and so on. This is not say, however, that these issues are not vital to CSCW and to understanding the role of representations, including MOIs, in work situations. Rather I wish in this paper to simply flag these reservations about a few of the implicit assumptions in *some* of the technologies of representation literature, but having noted these I wish to continue applying the analytic concepts offered by this literature in this case of photocopier development. In this way I suggest that we can retain our reservations while still being able to note the potential importance of notions such as the 'mobility of representations' for our understanding of the stipulation and mediation of distributed cooperative work.

Durability

To continue, the FRF is an enduring record which does not change appreciably over time nor as it is moved about. It is what Latour (1988) calls immutable. That is the FRF, filled in by a 'tech rep' survives, the journey and the wait until the Sunrise meeting of the next day when it is reviewed. This property of durability or immutability or persistence is of course necessary (though not sufficient) for a representation to have traceability. For example, in this project the FRF is summarized into the Daily report read out by the data analyst at the Sunrise meeting but if that meeting requires access to the original FRF then the data analyst has no trouble providing it - by tracing back and recovering the original. That is in editing the FRF into a daily report the original FRF is not lost and endures. This property of durability, which means that the FRF does not deteriorate over time, also means that representations can make the synchronous asynchronous and the immediate delayed. It means that the faults represented in the form of FRFs do not 'constantly interrupt' the other work activities of those who must deal with them (see also LANCS-2-7)

Flatness

Thirdly, the FRF is in some sense 'flat'. It allows a whole range of heterogeneous factors to be visually represented on the one plane of the FRF, in a consistent way and available at a glance. So for example on the FRF the electrical voltage, project policies such as waivers, physical paper trays and the like are all represented in the same way - as options to be circled; while humidity, age of the machine, call time, standard faults codes, people's names and the like are all represented alphanumerically - in one of the boxes of the form.

Each of these elements - such as quantifications of humidity, of time, of electrical voltage and so on - may be the product of considerable work separate from this particular project but these small ('technical') steps are brought together to make the FRF capable of re-presenting the circumstances of faults and corrective actions to the Sunrise meeting in a way adequate for the purposes of that meeting.

Abbreviation

Fourthly, the FRF representation is an abbreviation of the details and complexity of the fault and its circumstances. For example, one typical FRF we have read reports that the 'tech rep' spent from 15.15 to 15.59 mending the machine, yet the single sheet of paper which makes up the FRF is adequate enough to record all that we need to know about what went on during almost 45 minutes of working. The FRF representation is compact and economic for its purposes. That is representations such as FRFs follow a principle of condensation in that as much as is needed is condensed into as little as is necessary so as to enable ease and accuracy of perception and action. (Though of course as we noted the Sunrise meetings occasionally had to discuss whether the report had been over abbreviated and whether more information was necessary before decisions could be made).

We have heard how a typically abbreviated version of the FRF is read out as part of its parent representation - the Daily Report (while the fuller version in the FRF is available on demand from the data analyst during the Sunrise meeting). Interestingly, it also appears that the FRF artifact even contains within itself its own abbreviation. That is, the FRF form contains a section called the "short technical summary" which specifies the maximum length of the abbreviated version of itself. It states that this section must be "max. 44 characters".

Other Features

There are a number of other features of representations which authors such as John Bowers (1992a and 1992b) have pointed to in the work of Latour and others. These are relevant to the case we are examining here and to the work of Strand 3 on MOIs. However, for our purposes in this report these other features of representations can simply be stated without having to ground them in detail using the photocopier case.

These features include (i) being *reproducible* easily and at little cost and perhaps indefinitely, (ii) the whole or the parts being *combinable* and *recombinable* , perhaps freely[35] and in any order, so that relations between representations can be perceived visually, (iii) being able to be made *part of a written text* so that they can be commented upon and documented. There are no doubt others.

However in addition to the above consideration of the properties of the FRF, I also wish to consider in this report the place of the FRF representation in the overall organisation of the work on the project. Before doing this however there

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35 See also Garfinkel 1967 on freely combinable forms.

are a few brief points we can make about the way in which technologies of representation are useful in this case and generally.

3.3.2. More than cognitive amplification and economy

In the technologies of representation literature representations, such as the FRF, are seen as being intended to magnify capabilities and to compensate for deficiencies perhaps allowing us to do tasks and utilize resources for the first time. Additionally, representation technologies can, as for example Hutchins (1990) notes, be aimed at making activities easier and less effortful - by bringing the distant near, making the immediate durable and therefore delayable, by abbreviating complexity and so on. That is, the use of representations can be encouraged by a principle of economy which seeks information in its most convenient form and seeking material in its most pliable and wieldable form. In this way technologies of representation may both amplify capabilities and economize effort.

Indeed, deficiencies and/or difficulties may supply the purpose or stimulus for constructing a representation and/or for making it work in the first place. However, in saying this we do not then have to predicate deficiencies, bounded capacities (Simon 1955, 1957), difficulties and so on, just upon individuals. We can include groups and organisations themselves. Similarly we do not have to limit our explanations of these deficiencies to accounts described in terms of cognitive capabilities. So, for example, in a hypothetical situation where a project had to deal directly with faults rather than being able to work with FRF representations then it would be the project which was inconvenienced by having machines ‘off-test’ waiting for experts to arrive and examine faults directly. In this situation the inconvenience would incur costs for the project and produce difficulties in terms of time and money resources. Additionally, in such a hypothetical situation where the technology of the FRF was unavailable and faults had to be directly examined, we could imagine a whole range of difficulties that might be encountered by the project experts which arose from physical limits rather than cognitive capabilities. Faults occurring simultaneously on different machines located in physically separate test zone would for example produce difficulties associated with physically being in more than one place at one time.

3.4. The Ecology of Representations

Let us turn from considering the properties of the FRF to examining the place of the representation in the overall organisation of this project. We may consider, to adapt a term from LANCS-2-7, the ‘ecology of representations’ which infuse the organisation. By examining how the FRF is embedded in this ecology we hope to inform the issues of MOI identification and definition which have arisen in field work conducted in Strand 3. Let us consider some elements of this ecology.

3.4.1. Displacement along paths of representation and re-representation

The original FRFs are moved, or *displaced*, from the test chambers to the Sunrise meeting via the data analyst. They form the input for the data analyst's summarization of faults into the Daily report document. That is, the FRF representations are *re-represented* in the Daily Report . We can relate this to concepts in the literature on technologies of representation. For example Cooper (1992) suggests a view by which:

> "organizational activity becomes less a structure of discrete acts coordinated in space and time and more a series of displacements or transformations along informational networks".

As well as the displacement of the FRF along paths of representation and re-representation towards the Sunrise meeting, we can also note in the photocopier design project how other representations within the project feed into these paths and form networks or 'ecologies' made up of various representation technologies and artifacts[36]. For example, as well as operators reporting faults via FRFs, the engineers report back to the project about problems which have been solved, these are then noted in the project total displays, in diagrams showing the ratio of cleared problems to remaining ones and in other representations of the 'state-of-the-project'.

Additionally it is worth noting that, by changing the 'waivers' upon faults to be reported or by altering test rules and the test matrix, the project management in meetings such as the Sunrise can - at a distance - stipulate and mediate the activities of the test operators and 'tech reps'. This ability depends upon the representational paths *back* from the Sunrise meeting to the test chambers. That is to say that there are representational paths and that these have direction.

Finally, one other representation that was prominent in the networks within the photocopier project was the project schedule - a representation which originated from senior management 'top-down' before work began on the project. Such representations do remain regularly consulted and are therefore very much tied into the ecology of representations surrounding the project work.

3.4.2. Centres of calculation

We can note how many of the representations in these networks are sent to and collated by the data analyst. The analyst then puts them into an *order*, so for example the Sunrise meeting can review the faults machine by machine, in order of the age of the machines and in chronological order of the faults for that machine. The analyst also *summarizes* them so providing an *abbreviated* and manageable version of the previous days test operations in the Daily report - but without throwing away the original FRFs. Other statistics such as the ratio of cleared

36 See again the field study reported in LANCS-2-7 where the re-representational paths between various forms used in a work situation are clearly and diagramatically illustrated. They comment on the derivation and replication of information and how, for example, one form - the 'function sheet' - feeds into other representations - the staff roster, the diary, memos, the 'move forward file', door signs, timing sheets, the room layout, the hotel reservation sheets and marketing analysis.

problems to remaining ones can be *calculated*, and displays showing the slippage from targets represented in the project schedule can be produced. Similarly performance measures such as the time on test or the number of sheets feed through the machine, are *added up* into cumulative totals by the data analyst. That is we can describe the data analyst in Latour's (1987) term as one of the 'centres of calculation' for the project's organisation and its representations. Bowers suggests (in a description of the production of Government statistics):

> "at the end of this painstaking rerepresentation process policy relevant .. conclusions may become possible".

Similarly with the photocopier development project this calculation work performed by the data analyst contributes to the process of decision making, policy determination and management aimed at progressing the project. A particular occasion in which these activities happen is, as we have described, the Sunrise Meeting.

3.4.3. Multiple representations in the Sunrise Meeting

The Sunrise meeting is an occasion when the many representations used in the project come together - the problem lists, the FRFs, the Daily Reports, the Project Structure, and so on. Indeed the Sunrise meeting brought together a heterogeneous collection of people with specialist knowledge, representations of the previous days test operations, of the state of the project so far and its omni-relevance concerns, together with bits of broken screws and stained paper.

There are a number of particular points we can note about the mechanisms through which aspects of project organisation were made to interact and how the production and recording of problems was linked to the project's allocation and articulation of the further work to be completed

No single dedicated artifact

Firstly it is not clear from what we have said that, in this case, any one representation or single artifact could, on its own, independent from the rest of the representational networks, organise the cooperative work of the project and the allocation of work to be done or resources to be deployed. Rather the FRFs were necessary to feed into the Daily Report as the basis for problem identification and classification, classification that is on the basis of the critical/major/ordinary classificatory scheme, then problems had to be allocated to a machine part which then related to the project structure of specialist modules. Additionally, the distribution of problems across modules and hence the work load of a particular subgroup had to be displayed and monitored. It had to be monitored because if one area of the design was found to be causing all the project's problems then ultimately this was an issue for the whole project as it would be the whole project which was judged to be slipping from its overall schedule and the targets laid down in the project schedule.

In other words, the networks of interrelated representations brought *together*, often by the data analyst and often for the Sunrise Meetings, serve to support the articulation of the future work. Hence, while articulation tasks undoubtedly occur and are performed on the basis of representations and symbolic artifacts, in practice in this case it is not possible to point to a single dedicate artifact that alone acts as *the* mechanism of interaction.

Additionally, many of the representations described in this case have other functions to that of simply supporting articulation work. For example, the FRF not only feeds into a network of representations used for the identification of problems and problem locations in machine parts for which module teams are responsible, but the FRF also conveys specific information about the nature of the fault for those whose task will be to solve the design problem. That is, the FRF can be read by the Sunrise Meeting, in conjunction with the other representations we have described, for the purpose of identifying problems and articulating future problem solving work, but it can also be read by engineers in the carrying out of that problem solving work itself.

Alignments of representations

Secondly, in this case there were a number of arrangements by which the representations were, what we might call, 'smoothly aligned'. For example, the project structure (in which specialist engineers were grouped into 'modules') was linked to a description of photocopier machines themselves (in terms of parts or functions of those machines). That is, as we have described, these 'modules' were characteristically identified by the name of the part or function of the machine under development for whose design the module teams are specifically responsible, such as the 'stacker' groups and 'fuser' groups. In this way the various functional parts of the machine are associated with sub-groups of the project team, such that the terms 'stacker' or 'fuser' indicate *both* a part of the machine *and* a work group. Consequently, a part of the machine which is alleged to be the source of a problem is also the work group which is responsible for handling the associated problems. The allocation of a problem to a subsystem of the machine means that it is the responsibility of the work group representing that subsystem and therefore *the allocation of problems to machine parts is also the simultaneous distribution of further work tasks to project work groups*. That is, 'problems' are 'tasks' and problem locations in parts of the machine are task allocations to sub-groups or 'modules' of the project team.

It was around these interrelated representations and their alignments that the Sunrise meeting was organised and a 'management by problem solving' procedure was *able* to operate[37]. In this case, then, the articulation of work relied upon

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37 One might speculate that the alignment of these representations in this way made them harder to 'undo' or resist. Imagine a situation, for example, where a module leader wishes to deflect the allocation of further work to their team. In this situation it may be necessary for the module leader in the Sunrise Meeting to dispute the origin of a problem as arising from a particular *part* of the machine because it is at this point that work responsibilities are also simultaneously allocated. In other words, having agreed that a problem arises from, for example, the fuser technology it is then difficult to resist the automatic

bringing together and aligning multiple representations of the field of work rather than upon any single disembedded artifact.

3.4.4. Representations to answer questions

Much of what we have described above stems from the requirement that the project and individual engineers on the project ‘knew what to do’, knew what was their responsibility and what was others, could judge how well the project was going, could relate their work to that of others and so on. Let us call these the ‘what?’, ‘when?’,’ how?’ questions of doing cooperative work. It is for these types of questions that many of the representations are intended to provide relevant information, that is to speak to members’ questions about the work and its articulation[38].

The ‘to do’ list

One of the simplest of these representations was the ‘to do’ list. It was part of the network of representations and had all the features of mobility, durability, immutability, reproducibility and the like. Additional features are, of course, that items within a list can be ordered or categorized or grouped by arbitrary criteria, that once on a list the items stay until removed or crossed off (and in certain mediums such as paper that a trace may remain) and that items do (occasionally) get done and so lists change over time. In the photocopier project design problems were solved and crossed off the lists and problems were discovered and problem solving tasks were added to the lists. The objectives of engineers (and the project as a whole) were to clear their lists and consequently the lists relate to how much there is to be done and the work load that exists. This relates to an additional feature of representations the feature of being able to be *‘merged with geometry’* (Bowers 1992b) so that measurements and other calculations can be made. For example, with ‘to do’ lists adding up the number of problems on the list can provide information on work load. Other ‘calculations’ that can be performed on such lists are of course, to see if the list total is getting higher or lower, to see what is the ratio of ‘new tasks added’ to ‘old tasks cleared’ and to see what the rate of change is. The ‘statistics’ produced from such calculations help members answer questions about whether the amount of work is increasing or decreasing, whether they are running just to stand still or slipping ever further behind, whether they are slipping behind or plunging out of control, whether there is light at the end of the tunnel and so on.

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allocation of the problem solving task to the fuser team. The difficulty in resisting (or undoing) the work allocation stems from the alignment of the project module structure with the structure of parts of the photocopier machines. However this is a hypothetical example and further evidence would be required in order to ground this speculation. (See also Bowers 1992a on representation and scepticism).

38 Though as we note in COMIC-MAN-1-7 some representations, in this case a top-down process model, specify the ‘what’ and the ‘when’ but pass unresolved issues of ‘how’ down to those doing the work.

Informal calculation

While the project employed a data analyst to maintain the project's 'to do' list and to make formal and explicit calculations of about problem totals, and the like, the term 'calculation' employed in the technologies of representation literature is not necessarily restricted to formal mathematical or computational processes but can also be applied to the types of informal activities that individual engineers performed in looking over their own to do lists. Indeed the number of items (such as problem solving tasks) can often be *visually* inspectable - perhaps 'at a glance' - in terms of the list's 'length' and whether it is a long list or a short one. Similarly the ratio of cleared problems to added ones is reflected and visually displayed by the list getting longer or shorter.

In other words representing what needs to be done in the *format* of a list relates to the affordances of informal calculations[39]. [40] The format of the representation of the field of work does, however, generate certain requirements for the structuring of the phenomena of the field of work in its representation. For example, lists are lists of items and items are individual units, hence, the phenomena being listed have to be individuated for the purposes of representation. In this way units such as 'tasks' must be made to be relatively distinct and separate in order for their representation as 'items' in 'to do' lists[41]; though once phenomena are represented as items in a list they may be added up into totals, ratios may be calculated, and other such potentially useful calculations performed.

Situated meaning of the answers

The meaning of such statistics that can be calculated from representations are, of course, related to their context. For example, how concerned an engineer might be about having many problem solving tasks (a long 'to do' list), or indeed an increasing number of such tasks (a list that appears to be increasing), often *depends* on when in the life of the project this increase or decrease is occurring. For example, at the time the project was studied it was usual ('only-to-be-expected' and 'nearly-normal-for-this-phase of the project') for engineers to have a long list of unsolved problems, far more than they could be working on at the time, and steadily accumulating additional problems too. However, it was expected that problems would be accumulating more rapidly than they could be cleared, this being a 'testing phase' so the rate of identifying problems was expected to exceed the rate of solving them.

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39 See also, for example, Suchman and Trigg (1992) on the format of the 'complex sheet'. This representation has a matrix format which, together with a convention of reading it diagonally left to right and top to bottom, affords the conveying of a moving sequence of items despite it being a static paper artifact.

40 Consider also how in the Daily Report the FRFs are ordered on a machine by machine basis which affords the easy following through of the history of each machine and its malfunction events.

41 See also Chapter 2.4 on the CEDAC board where manufacturing problems are represented on individual cards.

3.4.5. The discipline of intermediatories

One final point is that, just as we can cross off an item from a 'to do' list without having in fact done the task, then so representations in general depend upon a certain discipline in their use. That a representation is only conventionally and symbolically linked to the phenomena, or that a MOI is independent of the FOW, has certain advantages as pointed out for example in the case of the Sunrise Meeting working with the FRF forms instead of the actual fault phenomena. However, a separation of representation from the actual events and objects it represents is also a separation from the discipline of nature and the world, the causal relationships between phenomena, the mutual exclusivity of certain events, and so on. When, as in the photocopier design case, the networks of representations depend upon the constant representational practices of intermediatories - such as testers filling out the FRFs - then the discipline of those intermediatories is vital to the functioning of the representations and the organisation and progress of the project which depends upon them. It is possible after all for the casual employees or the 'tech reps' not to fill out an FRF, not to send it to the data analyst, for the data analyst not to include it in the Daily Report and so on.

It is interesting to note then how some of these representations contain their own disciplinary instructions. For example, on the bottom of the FRF form, in bold capital typing, is "Engineers must complete FRF's on the day they are raised". Similarly the abbreviation practices are disciplined and the "short technical summary" section of the FRF specifies a maximum length for the abbreviated version of the FRF - "max. 44 characters". Additionally the test rules described above are there to discipline and govern the responses of operators to faults which may occur.

From this it should be recognized that this paper has focused (consciously) upon the *technologies* of representation but that the organisation of the photocopier project crucially depends upon the socio-technical complex of both technology and practice. The discipline of intermediatories is but one element of such associated practices.

4. Discussion

Mechanisms of interaction embody representations of the field of work as a basis for the articulation of distributed cooperative work which they stipulate and mediate. They are persistent artifacts independent of the field of work and aimed at supporting coordination tasks arising from the ever increasing complexity of cooperative working. This report has focused on a literature about technologies of representation in general, which includes representations used for articulating cooperative work but also representations used for simulating the external world, transforming boundary relationships, managing scale, making distant or opaque or intransigent material manipulatable, overcoming physical, cognitive and organisational limitations and so on.

I hope to have illustrated, using this case, a number of notions about representations from this literature. In particular observations about the general features of representations in terms of mobility, durability, flatness, abbreviation and so on.

Additionally I have pointed to the situation of representations within networks of other representations. That is networks of representational paths, paths from somewhere to somewhere else, paths that intersect and paths from many places converging together in centres. I have suggested that the representations move along these paths and that what moves along is an abbreviated form of that which is represented. In the case reported here these technologies of representation, their features and their uses add up. That is, bringing the outside world in, concentrating the faults, turning them into forms, moving representations along paths and through centres, abbreviating them, aligning representations and producing allocations of tasks in 'to do' lists and so on, these are the means by which the project is organised and distributed cooperative work made to work.

4.1. Identifying MOIs in the Ecology of Representations

In focusing upon the 'ecology of representations' I suggest that not only are we provided with some possibly useful notions (such as 'centres of calculation', 'alignment of representations' and the like) but that this approach of seeing representational artifacts as embedded within an organisational context, including other representation technologies, may inform our identification and definition of MOIs. That is, the theory of mechanisms of interaction and articulation work that is being developed in Strand 3 is also orientated to the practical and empirical study of work situations and the design of computational MOIs to support cooperative work[42]. In this way the identification of MOIs *in practice* and in specific situations is an issue for Strand 3. Following through the details of this case has suggested that while single dedicated MOI artifacts may exist in some situations, that in others articulation work may be supported by a range of interrelated artifacts brought together on specific occasions and made to work as an MOI. These component representations may also have multiple separate uses for other purposes including supporting primary tasks in the field of work.

4.2. Relating case studies

Additionally, some of the features of representations and the notions about the ecology of representations which I have illustrated in this report may input to the development of links and commonalties between a number of the case studies re-

42 Relatedly, Strand 3 work has always proposed that MOIs have existed for centuries and that computational MOIs might improve, not invent, them - just as CSCW has not invented cooperative work or articulation tasks. A parallel view is adopted in much of the technologies of representation literature which suggests that though electronic data can be made massively mobile, durable, abbreviated and so on, nevertheless, information technology is not special but rather encapsulates general functions of all formal organisation. Copper (1992) describes these functions and features of representation as simply hyperbolized with information technology.

ported in COMIC so far. So for example, I have noted a number of times in this report how observations made in LANCS-2-7 are similar to elements of the case, and its analysis, reported here. In particular LANCS-2-7 illustrates networks of paper forms within an organisation and in which information is duplicated abbreviated and derived from one form to another. I have commented how this may be related to paths of representation and re-representation. Similarly LANCS-2-7 describes how forms and their derivations are sent back and forth between departments in the organisation (one of the files is even called the 'move forward file') and we might relate these observations to notions in the technologies of representation literature about displacement and mobility. Additionally the study illustrates how an office in the organisation acts as a centre for many of these representations, a centre with its own ecology in the form of paperwork that fills the office and whose spatial layout constitutes, for those who can read it, a working 'map'. (These 'paperwork' studies have often provided extremely insightful and subtle observations about the affordances of the medium of paper, the spatial organisation of work, and so on and I point here to relations between COMIC case studies - not redundancies).

The potential also exists for links between a number of the Risø case studies and the study reported here. For example, as I have suggested the RISØ-3-18 study of the CEDAC board illustrates how blue print errors, part defects, manufacturing problems and issues and the like are recorded as 'post-it' notes which in turn are collated and classified and publically displayed in the CEDAC representation. I commented how these manufacturing problems and issues have to be individuated into separate notes or cards and that it is this individuation which makes the calculation of statistic possible, the visual inspection of problem totals practical and so on. Similarly, the RISØ-3-17 study of the Augmented Bill of Materials contains a number of interesting parallels to the case reported here and in particular the alignment of representations (and practices) to form an 'augmented' representation is described[43].

4.3. Links to Strand 1

General work on technologies of representation may also have a contribution to make to the explicit relating of Strands 3 and Strands 1. I have suggested that representations are embedded in organisational contexts and have organisational purposes. That is, our explanations of the usefulness of technologies of representation within organisations need not be restricted to explanations of their value to

43 A possible avenue to consider in the future is the relation between events like the Sunrise Meeting and the degree of alignment of representations. That is, *one* reason for bringing together representations for a meeting such as the Sunrise is in order to perform a number of translations and bridgings between one representation or representational path and another. For example, one of the tasks and purposes of the Sunrise Meeting was to read and interpret representations of faults (FRFs) and 'translate' them into representations of problems (problem totals, to do lists and the like). Perhaps with increased alignment of representations the translation and bridging work may be automatically or non-problematically undertaken without the need for a meeting. At this stage, however, this remains a rather simplistic speculation.

individuals and the amplification and economy of *cognitive* effort in terms of bounded rationality or similar notions. Focusing on technologies of representation in organisations and their usefulness for organisations, differs in emphasis from traditional organisational theory which is orientated to *information*, its costs (see Williamson on transaction costs), its value (see Schotter on the surprise value of information) and the capacity to handle it (see Simon on bounded rationality). Here we can draw on work such as Cooper's (see also Zuboff 1988) which suggests that organisations, work arrangements, projects and the like do not simply seek 'information' *about* their world, their market, their internal state, their production processes, their primary FOW, or about photocopier faults. Rather what he suggests is that we should see "organization as representation" and organizing as representing. By this Cooper (1992) means to emphasize that representation necessarily comes *before* information processing (though it is of course information which augments, or reduces, the power of representation as the representation's content or currency)

Cooper by highlighting representation as a "fundamental and mandatory act in the processing of information" points to those organisational structures, mechanisms of interaction or artifacts, such as fault report forms, not merely as structures and artifacts that convey and organise information but as representations which *construct* the *form* which information takes. In this way we should not, according to Cooper, just be concerned with information but with technologies of formulating, of representing, of giving form to and of formalizing information. (In the case of the FRF the information is literally represented in a certain form, a fault report form). The constructed form and format then affords, convenient manipulation, amplified and economic performance, extended capacities, reduced complexity and so on.

Additional links to Strand 1 work may come from pointing to (i) those representations in organisations which are associated with modeling the world outside of the organisation and bringing it inside (such as the test matrix and the test rules in the photocopier case), and also (ii) to those representations which are orientated to the modeling of the 'insides' of the organisation (the 'to do' lists, the project module structure and the like).[44]

4.4. Socio-Technical Arrangements

Finally it is worth stating again that I have focused upon the technologies of representation but that cooperative work is a socio-technical arrangement existing within an organisational context. That is, along with representations is representing. Hence, important issues remain concerning the making sense of representations, the relation of representations to local knowledge and the socially distributed nature of recipient knowledge, practices associated with making representations work, with maintaining representations, with creating them 'on the fly',

[44] These points have been expanded upon in the discussion of MOIs in Chapter 1.3.

with aligning practices with technology and with each other, and so on. A number of these issues are touched upon in chapter 2.6, MAN-1-5, LANCS-2-7, RISØ-3-15, RISØ-3-16, RISØ-3-17, RISØ-3-18 and RISØ-3-19 among others.

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Two comments on MOIs

James Pycock and Wes Sharrock

Manchester University

1. Introduction

We here make two proposals about the way in which the notion of 'mechanism' of interaction might be elaborated, ones which will make more apparent its consistency with themes and concepts being developed in other Strands of the COMIC project. We first argue that it is necessary to maintain the 'anti-essentialist' frame of mind which informs much of COMIC work, and thus avoid fruitless debates about whether some particular artifact is, or is not, *intrinsically* a Mechanism of Interaction. Secondly, we suggest some ways in which the study of 'Mechanisms of Interaction' may be informed by the employment of the 'performative' approach to organisation as developed by Bowers in Strand 1 (COMIC-MAN-1-4).

2. Anti-essentialism

In the examination of the articulation of cooperative work and devices used to support such articulation the notion of 'socio-technical' complexes may have some value for us. We may, of course, chose to begin an empirical study of a particular field site with an initial focus on the *artifacts* being used to articulate work - artifacts such as kanbans, project management applications, schedules and the like - but these artifacts are, as we have suggested in chapter 2.6, very much 'objects of interpretation' to be made sense of and to be operated relative to background information and points of view. With respect to the socio-technical notion we can observe that, for example, in the well known London Underground 'control room' studies of Heath and Luff (1992) they describe *both* the practices (or modes) of reciprocal awareness between operators in the control room and a number of the artifacts and technologies used by those operators to coordinate their work and the running of the Underground system. In this way it is not simply the reciprocal awareness of those in the control rooms that coordinates the work. Neither is it an artifact, such as the 'wall mounted line display', that coordinates the work. Rather it is the conjunction of these working together, for example the reciprocal awareness by one controller of another controller looking at the wall map, that gets the work done. That is there are both modes and mechanisms at play in this situation. Many of these points have been touched upon in Risø's work (see for example Risø-3-3) but we suggest could usefully be spelled out in the terms we are using here to elaborate certain aspects of the idea of MOI and to make explicit links to work in Strands 1 and 2. (We might also suggest that an avenue of further enquiry would be to look at the ways in which the technology is designed to provide shared awareness as with the 'public display' of the traffic map in the Underground as opposed to being built as a 'boundary object' like the FRF in chapter 2.6).

Following through the notion of 'socio-technical' complexes also allows us to draw out a number of points from the Strand 3 work so far and discussions concerning MOIs.

2.1. MOIs as a class of usage

Firstly, we have suggested that an artifact such as a MOI gets its sense and meaning from the situation and its usage. In this way that an artifact is a MOI is, for us, to say that it is used *as* a MOI. (This is not, however, to say that artifacts cannot be designed to be MOIs and nor to say that in practice an artifact cannot exist solely dedicated to supporting articulation tasks). The point for us is that we do not seek some 'essence' which certain artifacts possess which makes them MOIs, MOIs in all circumstances and contexts.

Relatedly, we suggest that those undertaking articulation tasks must manage with the resources they have to hand. (Indeed a number of the Risø field studies have pointed to the local innovation and adaptation of representations 'on the fly' to work as MOIs by those doing the work in order to be resources to get the articulation work done as best they can). If sophisticated dedicated project management tools are available so much the better, but if they are not then another symbolic artifact, perhaps in conjunction with others, may have to be made to work as MOI as best as possible. (Elements of chapter 2.6 and chapter 1.2 illustrate some of these points).

2.2. MOI features as comparative and relative

Secondly, we have suggested above that artifacts can be well or poorly suited (or designed) for use as MOIs and Strand 3 has successfully examined features of representations which may afford articulation work to varying degrees and contribute to the suitability of an artifact to be used as a MOI. That is features such as malleability, flexibility and so on. (Chapter 1.2 also suggested a number of similar features of representations in general that are highlighted in the 'technologies of representation' literature, features such as mobility, durability and so on).

However the features of representations and MOIs are not inherently, say, 'flexible' or 'mobile', for the determination as to whether something is 'flexible' or 'variable' is comparative and relative to circumstance. In other words, a particular representation is not flexible or mobile while another representation is inflexible or immobile. Rather one is *more* mobile than the other. (In chapter 1.2, the FRF is more mobile than the photocopier malfunctions). The attributes of MOIs, then, are variable and relative.

Additionally, however, the attributes of MOIs are also relative to circumstances. That is, one representation, artifact or MOI is only more mobile, or more flexible than another representation or phenomena depending upon the particular situation and the socio-technical complex of which is it a part. In this way features such as mobility or flexibility are relative to the forces trying to prevent movement or change.

For example, while we may say that a map of a mountain representation is more mobile and easier to move than the actual mountain itself, we are saying this relative to default circumstances. It may very well be easier to take a pick and shovel to the nearest mountain than to move a map out of our University library. More seriously maps and their mobility can be under the strictest of military and security restrictions in areas such as sensitive national borders.

Similarly, we suggest that it is not the case that one MOI is ‘malleable’ while another is not, rather a MOI may have more or less malleability than another, and more or less malleability relative to this or that situation, situations in which the forces for and against redesigning the structures and rules that constitute the MOI vary. In this way flexibility, mobility, malleability, durability and the like are not, for us, inherent ‘essential’ properties of the artifacts constant across all circumstances and quantifiable in the abstract.

2.3. Debatable ascriptions to the social and the technical

Finally we wish to suggest that the issue of deciding what is a MOI (or a property of a MOI) and what are the conventions of use associated with the artifact, what is essential to the technology and not elements of the practice associated with it, what can be attributed or ascribed to the representation and what to the ‘discipline of intermediatories’ (see chapter 1.2), these issues are for us debatable. Indeed debates such as these occur within organisations and are part of organisational change (see for example MAN-1-5).

This may be particularly so in organisations trying to decide the location of a problem, whether it lies with the technology or with the practice surrounding it. So as an example David Bogen (1994) recently described a case concerning ‘party-lines’. These are multi-party telephone lines in which distributed people come together to share a ‘virtual audio space’ to discuss topics of common interest, often of an ‘adult’ character. He reports how one of the central issues with the party lines is that it is difficult to know “who is out there”. That is people often dial-up the party-line and listen in to others talking without making their ‘presence’ known. There are occasions, he reports, were a number of people are connected to the party-line but no-one is speaking or making their presence known to others. This situation often continues until someone else begins to talk, at which point others join in and the level of talking rises. His tapes of these discussion are full of repeated utterances such as “anyone there” that meet with no response. However, when responses do occur (for example as a result of a silent listener recognizing from previous ‘parties’ the voice which is asking “is anyone there”) then it suddenly becomes clear that there are many others in the ‘space’ - others who at this point join in with comments such as “hi I’m here too”, “yer I’m around”.

In this case it appears to be debatable whether the origin of the difficulties[45] of ‘knowing who is out there’ lie with the technology (the telephone) or with the conventions and practices associated with joining a party-line (the silent overhearing). In many ways it is open to attributing to either. If we imagine a desire to overcome this difficulty of knowing who is out there then we can imagine either a new party-line technology with some form of signaling that indicates how many others are in the space. Alternatively we can imagine adaptations to the conventions and practices of taking part in party-lines by which participants make their presence known (and the studies of, for example, Heath and Luff (1992) have demonstrated some of the subtle and minimally disruptive ways in which this can be done). That is, we suggest that there is in this example no single, definitive, inherent and essential ascription of the problem to either the technology or the practice, to either the social or the technical, to either the modes or the mechanisms[46].

3. Top Down and Bottom Up

A persistent focus of controversy within the social sciences, especially sociology, is the extent to which analysis is to be organised on a ‘top down’ or ‘bottom up’ basis, or, to form the issue in another way, employing Marxist terminology, the extent to which analysis must be structured around a concept of ‘the totality.’ The debate is over the question of whether the analyst must seek to view the activities of society’s members relative to a conception of an over-arching arrangement of which those members or a part, must seek to understand particular activities and situations relative to some encompassing and organising ‘whole’? Controversy only arises if the question is treated as being posed in such a way that it must be answered either correctly or incorrectly, rather than one which asks about *strategies* of investigation, with the possibility that investigators could pursue *both* possible responses to it, seeking to articulate analyses which deploy a concept of ‘totality’ or, equally legitimately, those which dispense with such a concept. We

45 Clearly there may be many reasons why those taking part in these lines wish to maintain their silence at times and many reasons why those selling time on party-lines benefit from time spent finding out who is out there, but let us assume for the purposes of this example that there is a ‘difficulty’.

46 Interestingly in discussing this difficulty with party lines Bogen ascribes the cause to there only being a ‘single channel’, a term that is perhaps somewhat usefully ambiguous as to whether it refers to the ‘social’ conventions of turn taking or to the ‘technical’ limits of this telephone technology. Lea (1993) has similarly commented on how terms such as ‘bandwidth’ are becoming used to both refer to the technical capabilities of bits per second transmitted down communication lines and also to refer to the social differences between face-to-face, video-conferencing and computer mediated communications.

certainly intend to treat the question as posing problems of strategy, in recognition that the prevailing modes of analysis within the COMIC project are those which derive from approaches which seek to operate without a concept of totality, which do not, in current terminology, seek to engender a 'grand narrative'.

The argument as to whether one should, and with what costs and disadvantages, employ a concept of 'totality' is one which has pervaded the social sciences and which has, therefore, found expression in organisation theory, and Bowers' attempt to articulate a notion of 'performative organisation' in Strand 1 and Pycock's 'Technologies of Representation' contribution to Strand 3 (chapter 2) both continue the exploration of the idea of a 'bottom up' approach to organisation rather than the prevailing 'top down' conception. See also Calvey's paper on the notion of 'post-modernism in organisations' (COMIC-MAN-1-9) and considerations about the 'embeddedness' of organisational activities in Strand 2's deliverable (COMIC-D2.2).

3.1. Organisation-as-a-whole

Morgan's influential survey of the range of organisation theories, conceiving them as a set of 'metaphors'. clearly indicates that these are overwhelmingly designed to offer a conception of the 'organisation as a whole', as, for example, with the attempt to conceive the organisation as, effectively, a machine, a functioning assembly of constituent parts, whose functioning can be improved through a 'fine tuning' of the interactions between those parts. The activities of members of the organisation are, therefore, to be understood relative to their placement within the 'organisation-as-a-whole' , and, of course, relative to the ways in which the composition of that whole is conceived. By contrast, the notion of 'performative organisation' involves *the analyst's* dispensation with the notion of 'organisation-as-a-whole.' Its mode of analysis is not directed toward producing the *analyst's independent* conception of the organisational totality, but this does not involve the dispensation with the notion of the *organisational totality*, for, of course, it is recognised that members of society, participants in organisational life, themselves deploy notions of an organisational totality. It was, for example, a crucial part of Egon Bittner's (1965) ethnomethodological critique of organisational theorising - which is influential on the 'performative conception' - that there was an ambiguous relationship between the concepts of organisational totality employed by theorists and those indigenous to organisational activities themselves. The adoption of the 'performative conception' alters the problematic, treating the problem of conceiving 'the organisation-as-a-whole' as one which is *internal* to organisational affairs. The 'performative conception', further, does not treat that problem as one which is of a purely 'cognitive' kind, but, as its very name indicates, treats it as one which is concerned with the problem of conceiving the organisation as a totality *in relation to the organisation of social actions*.

The 'performative conception' is also formatively influenced by the 'post-modernist' concern with the heterogeneity of 'voices' which speak from within social settings, and thus seeks to emphasise the diverse, and even conflicting, ways in which 'the organisation as a whole' may be conceived.

On the basis of such conceptions we could pursue, for example, our investigations of 'Business Process Re-engineering' (see COMIC-MAN-1-7) backed up by process modelling representations in terms of the rhetorical character of its formulations of the organisation-as-a-system-of-processes, orientated to and justified by the need for organisations-as-a-whole to survive, to compete, to learn, to adapt and so on, with its devices functioning as mechanisms of interaction which putatively make 'the-organisation-as-a-whole' visible *from within the organisation* and which facilitate the articulation of work vis-a-vis the 'fateful' contingencies of organisational work.

3.2. Turn to the inside

Put at its most simple we can say that 'nasty surprises' can be very costly to organisations, perhaps even life threatening. That is, sudden changes in the market, in consumer demand, in supply sources, in regulations about products, and so on, threaten to catch an organisation, company or business off guard. For this reason organisations expend great efforts monitoring, modeling, predicting, analysing (even controlling) market demand, opportunities and changes happening outside their 'walls'. (Organisational theories, such as that of Schotter's (1981), have recognized this, even suggesting that which *is* information is that which *has* surprise value. Consequently for these theorists the purpose of arrangements like organisations is to keep some control on and avoidance of surprises). There is, however, another way to reduce the dangers of 'nasty surprises' and that is to improve responsiveness to changing situations. It is this second strategy that is being heavily promoted today in new management approaches such as BPR as the way forward for organisations to change to survive in the modern business environment. We hear how production should respond to the 'pull' of the market, to be timely rather than blindly seek to push out products in the hope that markets exist. We hear how businesses should re-engineer their internal processes to improve speed and flexibility. We hear how concurrent engineering can cut down response times, we hear how organisations need a certain requisite variety in their production in order to maintain the capability to adapt quickly, we hear the benefits of just in time manufacturing and low inventory levels, we hear of the benefits of lean, fit, downsized and outsourced organisations and so on.

Let us name this a 'turn to the inside', a turn from representing and modeling the external world of the market environment and to the internal market of the organisation.

The BPR approach, in making its turn 'inside the organisation' retains, nonetheless, the assumption that it's objective is to speak 'for the organisation as a whole', and that its representations are, therefore, 'transcendental' ones and retain, therefore, the 'rationalist' conception of the organisation as unproblematically unified and uniformly motivated. The 'performative' conception seeks, however, to locate such modelling *within* the organisation, as one amongst a variety of -possibly - contending 'voices' and therefore seeks to situate the models themselves within the organisational world. The BPR approach, underpinned with process modelling notations, tends to assume the top down prescription of organisational change, and the unproblematic isomorphism between the computer sequencing of operations and the organisation of the flow of work.

3.3. MOIs inside organisations

COMIC's concerns with cooperative work occurring within organisational contexts similarly relates to this 'turn to the inside' and furthermore the Strand 3 work especially concerns the coordination and articulation of the inside workings of processes. The ever increasing need for greater responsiveness and the introduction within organisations of concurrency, parallelism, distribution of sources of production and so on bring with them associated demands in the form of articulation tasks such as scheduling, integrating, monitoring dependencies and the like. Attempts to understand mechanisms of interaction are therefore entirely congruent with a 'turn to the inside' in search of greater responsiveness. However, while the concerns of COMIC and particularly the issues in Strand 3 have similarities with the concerns of modeling techniques such as BPR, we must also relate our COMIC work to a number of the points we have made above. That is, points concerning not only relations between formal mechanisms and informal procedures but also:

- the relationship of representations to the organisation-as-a-whole,
- the location of the modeling within or without of the organisation and
- the top-down prescription of change

We suggest then a number of points for consideration in the investigation of mechanisms of interaction and their relationship to organisational contexts. These points concern:

- how the MOI is to embody/implement an orientation to - if not a conception of - the organisation-as-a-whole,
- what the relationship is between the organisationally uniform functions and local innovations and modifications and
- the extent to which it is necessary to constrain local innovation to conform to organisational uniformity

Put another, and final - for the moment - way, we are suggesting a convergence of interests within COMIC concerning the relation between 'top down' and 'bottom up' ways of organising the organisation's work, how these ways are supported and how they are legitimated.

3.4. Legitimating the local level

With regard to the latter issue - the legitimation of considering bottom-up organisation - we have in Strand 3 highlighted the need for the existence, manipulation and modification of MOIs at a local 'bottom-up' level in the work process. We have suggested that the ever increasing needs for improving the articulation of the cooperative work inside an organisation require that:

> *"the full resources of cooperative work must be unleashed: horizontal coordination, local control, mutual adjustment, critique and debate, self-organization. Enter CSCW." (Risø-3-3 p11)*

This is in contrast to some BPR approaches which have rejected ''bottom-up' approaches to improving and supporting work processes, suggesting alternatives involving radical top-down and organisation-wide changes (see Hammer 1990 and Hammer and Champy 1993, though contrast with Davenport 1993a and 1993b). It is interesting to note then the different reasons given to legitimate the consideration of 'bottom-up' organisation. That is, in addition to the many arguments within CSCW based around the local interpretation of representations and the situated nature of action, recent approaches even within process modeling have drawn attention to the need for local, we might say participatory, approaches to work representation and MOIs. The BPR writer Thomas Davenport has stressed the need for both bottom-up process improvement and radical process innovation and, interestingly, a newly developed workflow system - the Regatta system (Swenson 1993) - attempts to support the linking of locally modelled and modified process models to high-level top-down workflow representations. The need for local 'bottom-up' modeling in addition to top-down representations is accounted for by Swenson on the grounds that (i) we cannot allocate or assume an overall, omniscient view of the organisation from within the organisation, (ii) that we cannot assume that the process is (or can be?) known in all its details before its enactment can be begun.

Related developments in organisation theory (see for example Wardell 1992) are proposing greater consideration of the "practical autonomy" of labour at the points of production which shape the form and transformation of work arrangements. That is, the local level of the work place is seen as "an emergent frontier" for organisational change. This research highlights, through an historical analysis of transformations in work arrangements, how organisational changes, representations of the field of work and other artifacts have been introduced and prompted by the practical autonomy of labour which can make problematic the fulfillment of managerial 'top-down' objectives.

Our concern then has been to point to the strategies of investigation and representation of organisation - top-down. bottom-up, in totality, with a heterogeneity of voices and so on - and to relate these concerns within COMIC and elsewhere not only to the work in Strand 1 (particularly on process modeling) but also in our consideration of mechanisms of interaction situated in organisational contexts. We have also been interested to note some of the reasons for considering the 'local level' of cooperative work which have recently emerged in a number of areas.

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COMIC REFS
MAN-1-4
MAN-1-5
MAN-1-7
MAN-1-9
MAN-3-2
MAN-3-3
RISØ-3-3

Part 2

Mechanisms of interaction — Case studies

The construction note

Hans H. K. Andersen

Risø National Laboratory

This paper reports in a descriptive manner on how a form is used in a large scale manufacturing company for the articulation and propagation of changes regarding products, parts, processes, prototypes and informational objects. The construction note is a mechanism used within the company to handle and distribute semi-structured messages and notes regarding product changes and to handle and distribute proposals for product changes. Also it is used as a basis for delegation of responsibilities and tasks, and to a certain degree control of inventories, processes, machining and measuring tools.

1. Introduction

The production of technical documentation in a large scale international manufacturing company is a highly complex activity. It involves a large number of people, who are scattered, not only around one factory site, but world wide. Moreover these people are mutually interdependent in their work and they carry with them a whole range of different perspectives, objectives and competencies into the work process.

This paper is based on a resent field study at a large scale manufacturing company (Andersen, 1993). The field study focuses on the production of technical documentation related to new product development. Naturally this has implication to the perspective taken regarding the analysis brought forth here. The analysis is based on data from interviews with technical writers, engineering designers and technicians (the engineering technicians interviewed are employed only to work with the construction note) plus document analysis of a large number of construction note examples.

Omega produces machining components. In its field it is amongst the three leading companies in the world. It employs around 8000 people in more than 30 countries. The main management, administration, production, product development and marketing activities are located at one site in Denmark

Since even the smallest change to products under development has implication for an immense variation of activities within the company, e.g., the production of technical documentation, it is necessary to distribute and in some way handle the distribution of information regarding such changes. A mechanism -- the construction note -- was invented. The construction note is a mechanism used within the company to handle and distribute semi-structured messages and notes regarding product changes and to handle and distribute proposals for product changes. Also it is used as a basis for delegation of responsibilities and tasks, and to a certain degree control of inventories, processes, machining and measuring tools.

The construction note has rules for operation, control, archiving, flow of distribution, authority of use, and how actually to fill in the form. In most cases the procedures and rules are to a high degree followed. But in some cases they are circumvented for example if a note of change has to be to be discussed in more dept. An estimated number of original sheets produced each day in the company exceeds 500 in number. These are copied and send to various sorts of recipients within the company. In one department an engineering designer on the average distributed 3.6 kilograms of paper sheets a week. The construction note sheets are distributed using internal mail, conventional mail and fax machines. The form itself is produced and maintained on CAD-workstations.

The paper present first the research approach taken then the physical appearance and the basic use of the construction note will be described. Next the procedures, states and triggering conditions of the social mechanism of interaction will be discussed in some detail. The last section deals with the description of the objects and functions of articulation work embedded in the mechanism.

2. Research approach

The field study focuses on the identification and analysis of the characteristics of social mechanisms of interaction and articulation work in the production of technical documentation, related to new product development. The study spanned a period of three months of which sixty days where spend at the location. The techniques used were:

- Interviews (qualitative, unstructured).
- Observations (activity sequences, conversation, discussions, participation in meetings etc.).
- Document analysis (company standards, handbooks, technical documentation, lists, diagrams, drawings etc.).
- Still-video takes (interior, archives, computer displays, work situations, computer equipment, etc.).
- Participation (involved in work activities and decision making, recommendations).

Currently 25 persons has been interviewed at length (45-130 minutes). In addition a number of focused short interviews (length 5-20 minutes) have been carried out. The majority of these interviewed were located in the technical documentation department while others were located in several different departments (development, product management, computer services, quality, construction and marketing). The research approach is qualitative in nature and is inspired by Work Analysis (Schmidt and Carstensen,

1990) as well as an ethnographic approach, e.g., (Hughes, 1992) , (Atkinson, 1990) and (Hammersley and Atkinson, 1983) The interpretation of the findings will take as a point of departure the concept of mechanisms of interaction (Schmidt, 1993)

> "A mechanism of interaction can thus be defined as a symbolic artifact that serves to reduce the complexity and cost of articulating the distributed activities of a cooperative work arrangement by *stipulating and mediating* the articulation of the distributed activities"

Furthermore the mechanism must be a symbolic artifact which is standardized in format. This paper will investigate the construction note in the light of the concept of mechanisms of interactions, i.e., what procedures and conventions are involved? How is the construction note transformed in the process of articulating distributed cooperative activities? What is the relation between the procedures, states and triggering conditions brought into play in using the construction note?

2. Physical appearance and basic use

The construction note (CN) is an is an A4 paper-based form where both sides of one sheet of paper is used (see fig 1). A tick off in the square boxes in the topmost part of the form (segment A) indicates whether the note has to be regarded as a proposal for change, a change note or a message. If the CN is classified a proposal for change (1), the date of issue, the initials and department number of the actor(s) who are making the request for change, the expected effective date of the change and a deadline for answering will be stated. If the form is classified as a change note (2) the date of issue and the effective date of the change will be stated. If the CN is classified as a message (3) only date of issue will be stated.

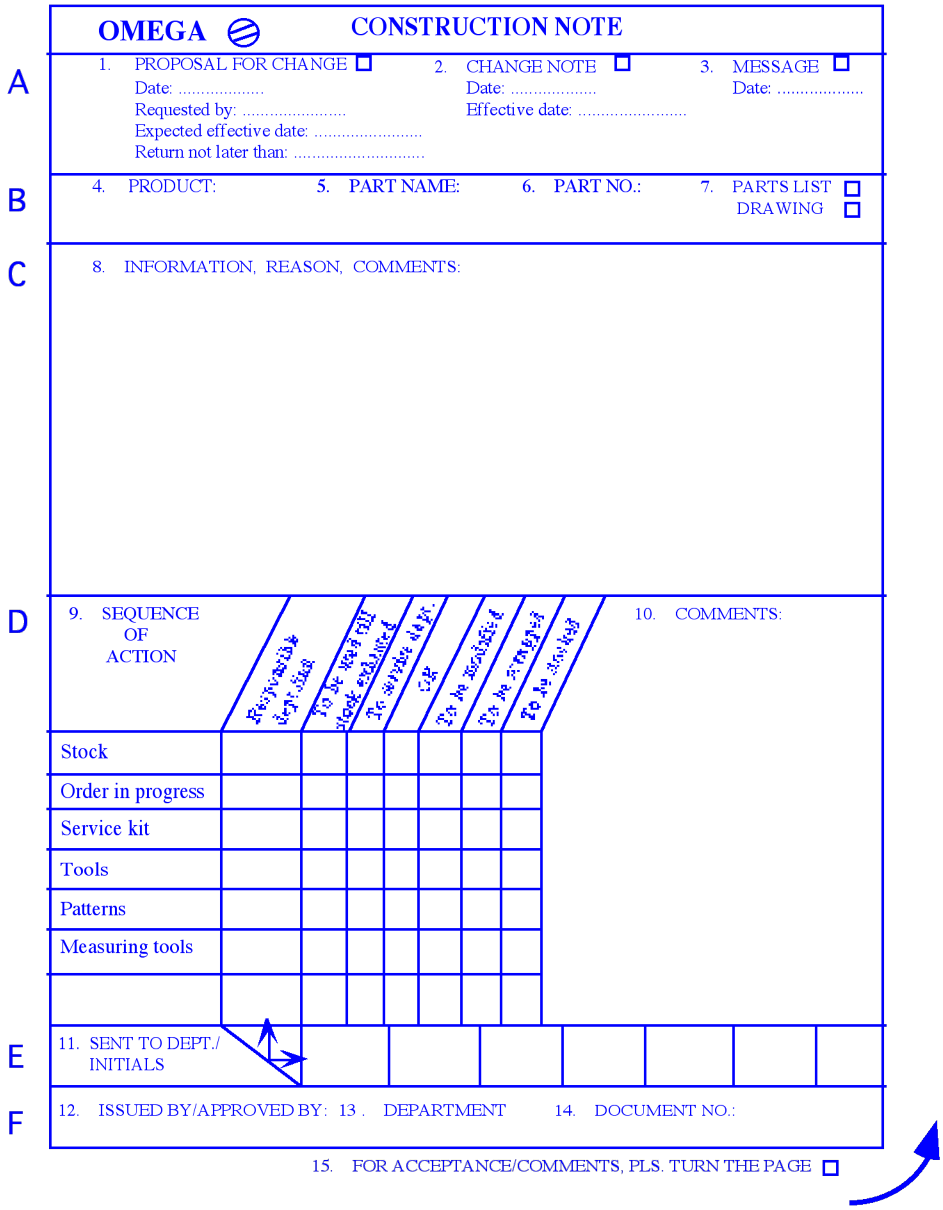

Figure 1: The construction note form. The leftmost capital letters serves the purpose of the analysis given. They are not part of the form.

In segment B the product specification (field 4) is stated for example UMT (D) / UPT (D). In the part name and number fields (5, 6) the product or component designation is stated. The designations are taken from the parts list. The square boxes (field 7) are used to indicate if changes are made to the parts lists and/or drawings (CAD-models) concerning the product/component in question.

The description field (8) in segment C is used to give formal and semi-structured information, reasons and comments regarding the product change or proposed product change. If the CN is classified as a change note information must include the situation before and after the change. Also in this case a short description of the reason for the change must be stated. In segment D the sequence of action (field 9) agreed upon by the engaged parties has to be stated. For example if the field “Measuring tools” is ticked off in the field “To be scrapped” it could mean that a new measuring tool has to be developed because of a change in the actual measuring tolerances. The sequence of action can be determined by using the proposal for change or message version of the CN. But the phone is an important tool especially in regard to very narrow time limits. A person is made accountable for developing the measuring tool by the engineering designer by entering his or her initials. The sequence of action field is important in analyzing archived CN’s in order to determine what went wrong in the process of major changes. The comments field (10) is used to further comments regarding specific action sequences.

In segment E the department number and initials (field 11) of the recipient of proposal for change and messages are stated. Regarding recipients of change note versions only the ones not on the specific distribution list are stated.

In segment F the person responsible for filling in the CN and the person responsible for approving the actual process or product state their initials. The department number (field 13) is given for the process or product responsible person. The document number field (14) is used only in the change note version. The number consists of to letters and a four digit successive number. The letters specify the responsible product group. The number can be extended to indicate how many change notes that has to do with one singular case. For example the document number LP 0767 3/10 means that the case LP 0767 has triggered off 10 change notes and in this case it is the 3rd change note out of ten. The document number is used in archiving change note versions. If a CN is distributed as a proposal for change or a change note a tick off in the acceptance/comments box (field 15) means that comments and eventual acceptance or rejection from decision makers must be stated on the reverse page of the CN.

3. Procedures, states and triggering conditions

The description of the mechanism will fall in three parts -- the proposal for change note, the change note and the message facility. This is not to say that these features of the mechanism are independent of each other on the contrary the features are highly interconnected so the division into three parts is done for analytical purposes. The description is mainly based on the use of state-transition diagrams, relating states, fields in the form and procedures to each other, and determination of the triggering conditions for each transition.

The construction note mechanism is mainly used by engineering designers, technical writers, product managers, production engineers and tool designers. Since the focus of the field study was on the production of technical documentation only the people directly involved in this production will be briefly described here, namely the technical writers and the engineering designers.

1. The technical writers.

The technical writers are engaged in the transformation and mediation of technical information that is the produce, translate, control translation activities, update, maintain, develop, archive, co-ordinate distribution, store and distribute technical documentation. The technical writers investigate and transform change notes. They produce modification notes on the basis messages and change notes. They posses general knowledge of the whole range of products. They archive change notes. The technical writers typically have a craftsman practical education combined with a short theoretic technical education.

2. The engineering designers.

   The output of the engineering design activities is, e.g., CAD-models, performance data and various other forms of product data which is utilized in the technical documentation production. The engineering designers are key persons when it comes to product analysis information. They are involved in scrutiny meetings and review of technical documentation. The engineering designers recognize, distribute notes on and control changes to products, processes, data, etc., in the product development phase. They control the articulation of tasks and activities regarding these changes. On the basis of input from various departments they control the destiny of proposals for change. They archive proposals for change, change notes and messages. Some engineering designers have a bachelor degree in mechanical or electric engineering while others have a master degree in civil engineering. They are supported by engineering technicians who typically have a craftsman education combined with a shorter theoretical technical education. Also the engineering designers are supported by draught's people.

3.1 The proposal for change

The purpose of a proposal for change (figure 2) is to ensure accept from different departments before essential changes is carried through. It is used if it is estimated that wanted changes regarding, materials, components, products, processes, etc., will have essential influence on other departments' activities. It is used by all departments, i.e., service, quality management, product management, marketing, production, construction, technical documentation, etc.

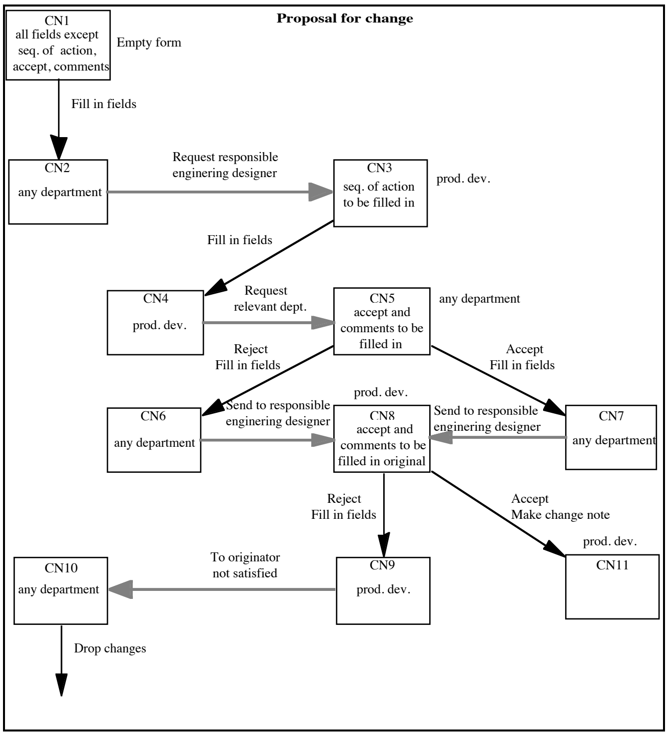

Figure 2: State-transition diagram for the proposal for change version of mechanism. Each box in the diagram illustrates the possible states of the proposal for change part of the mechanism. Black arrows illustrate changes to the content of the mechanism, i.e., it is updated while gray arrows indicate the triggering condition for changing and updating the mechanism.

The general procedures for using the proposal for change are:

(1) A need for change of for example products, parts, drawings, parts lists, tolerances, etc., is recognized and a form is filled in by for example an engineering designer, engineering technician, draught-man/woman, production engineer, technical writer, quality manager, etc. All fields related to a proposal for change except the sequence of action, accept and comment's fields have to be filled in. This procedure relates to CN2 in figure 2.

(2) The form is send as a request to the responsible engineering designer in the product development department. Who to send the request to is decided on the basis of the categorization of product groups in regard to the classification of the proposed change (state CN 3 in figure 2).

(3) The responsible engineering designer is hereafter in charge of further processing of the proposal for change. He archives the proposal for change. The engineer classifies the actions needed and fills in the "sequence of action" fields on the basis of negotiation with responsible actors in departments that will be influenced by the proposed change. Exactly which department that will be influenced is partly decided on the basis of distribution lists and partly decided on the basis of "common sense" conventions (CN4 in figure 2).

(4) Copies are made and requests send to the relevant departments (CN5 in figure 2).

(5) Responsible actors in the departments decide if they approve or disapprove the proposed change. In either case they must comment and give reasons for the decision taken (CN6 or CN7 in figure 2). Comments may be hand-sketched drawings, engineering calculations, excerpt from tolerance tables, bill of materials, survey parts lists, text, etc.

(6) The form is send back to the responsible engineering designer (CN8 in figure 2).

(7) On the basis of the returned proposals for change the responsible engineering designer analyses the consequences of change and decides whether or not to accept. If accepted a change note is created. If rejected the copy of the original proposal for change is commented.

(8) The proposal for change is sent back to the originator (CN9 or CN11 in figure 2).

(9) The originator drops the actual proposal for change (CN10 in figure 2).

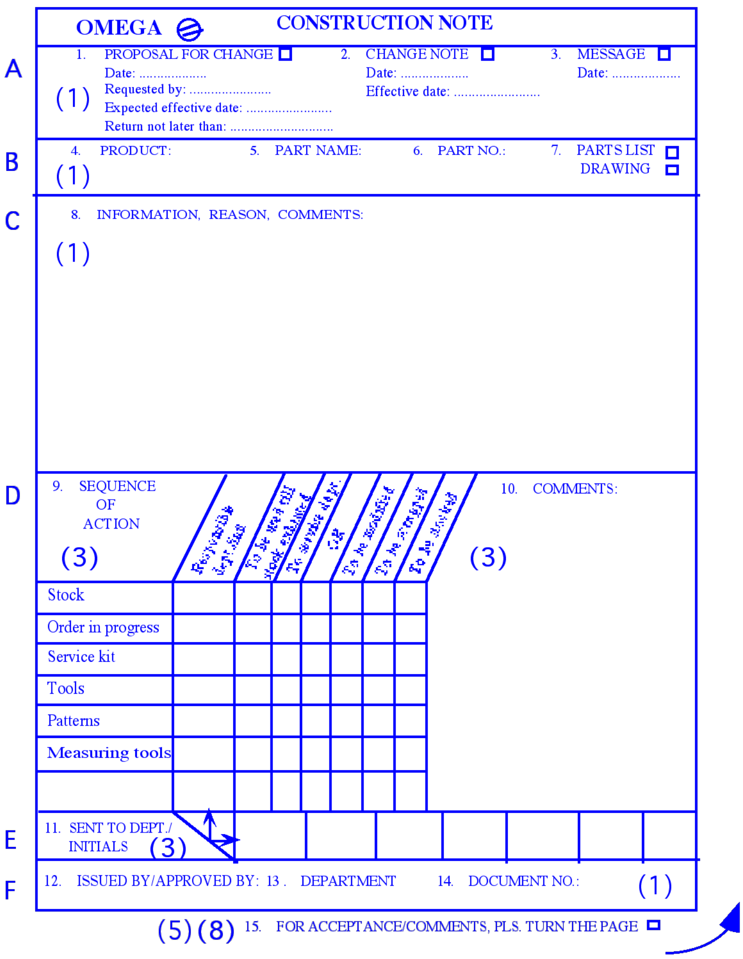

Figure 3: The proposal for change version of he construction note form. The numbers in round brackets relate fields in the form to procedures for using the construction note mechanism.

3.1.1 Triggering conditions for the proposal for change

The triggering conditions for the proposal for change are listed below.

CN1: There is a transition from CN0 to CN1. This transition is triggered by wanted changes in the field of work for example to introduce a new lubricating oil for servicing a certain type of product series. The person responsible estimates that the wanted change will have implications for activities in other departments and fills in the form as a proposal for change note and sends it as a request to the engineering designer responsible for the product in question.

CN2: See CN1

CN3: On the basis of the form received the engineering designer decides which departments should engage in the further processing of the wanted product related change. Using distribution lists he decides which people should be involved. On the basis of negotiation with these people a sequence of action is determined and then stated in the form. The form is copied archived and finally distributed as requests to the people in question.

CN4: See CN3

CN5: Two transitions are possible. The recipients decide whether the proposed change is acceptable seen from their point of view on the basis of their special knowledge regarding the product in question. The transition CN5-CN6 is triggered if the change is rejected. Fields are filled in and information is added regarding the causes of rejection. The transition CN5-CN7 is triggered if the change is acceptable. Fields are filled in. In either case the proposal for change is returned to the engineering designer in control.

CN6: See CN5

CN7: See CN5

CN8: Two transitions are possible. On the basis of the state of the returned and changed proposals for change the engineering designer in control decides whether to accept the proposed change. The transition CN8-CN9 is triggered if it is decided that the proposal for change is rejected. In this case fields are filled in regarding the cause of rejection. Finally the proposal for change is send back to the originator. The transition CN8-CN11 is triggered if it is decided to accept the proposal for change. In this case a change note is created (see section 3.2.1, CN1).

CN9: See CN8

CN10 The originator accepts and drops the actual change.

CN11: See CN8

3.2 The change note

The purpose of a change note (figure 4) is to ensure that necessary activities in relation to a change are initiated sufficiently early to be done when the announced change takes effect. This leaves time to others involved in the engineering design activities to adjust their plans and activities according the change in question. It is distributed for any extension, restriction or change to the specification of quality assurance instructions, bill of materials, raw materials and drawings (CAD-models) of the product in question. The technical writers use the change note as a basis for the creation of a modification note with more detailed information regarding the changes in product specifications. The modification is distributed both within the company to relevant persons as well as it is distributed to certain types of customers. The modification note has to be accepted by the development department before distribution.

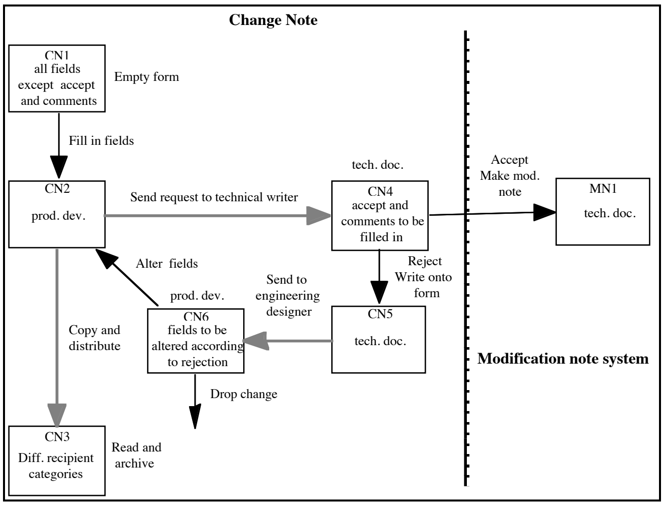

Figure 4: State-transition diagram for the change note part of the mechanism. Each box in the diagram illustrates the possible states of the change note part of the mechanism. Black arrows illustrate changes to the content of the mechanism, i.e., it is updated while gray arrows indicate the triggering condition for changing and updating the mechanism.

The general procedures using the change note are:

(1) The responsible engineering designer reports on changes to for example drawings, products, engineering calculations, etc. and archive the change note All fields related to a change note except the acceptance and comment fields has to filled in (CN2 in figure 4). A sequence of action has to be stated. This sequence of action is stated as a result of negotiatons between the engaged parties.

(2) Copies are made and distributed to development, production, construction and technical documentation departments within the main company site as well as to subsidiary service, production and sales companies around the world on the basis of a classification of the change in question. Distribution lists as well as “common sense” conventions are used (CN3 and CN 4 in figure 4).

(3) The technical writers investigate if the change will have general implications for the whole range of product types. On the basis of this investiga-

tion the change note will either release a modification note or get rejected. In the last case the result of the investigation has to be stated in the change note. A proposal for a new sequence of action will be included (MN1 or CN5 in figure 4).

(4) The change note is send back to the originator (CN6 in figure 4).

(5) The responsible engineering designer then either alter fields and design according to the rejection stated by the technical writer (CN 2 in figure 4) (for example, often the sequence of action design has to be reconsidered), and redistributes the change note (CN 3 and CN4 in figure 4), or the engineering designer decides to drop the change.

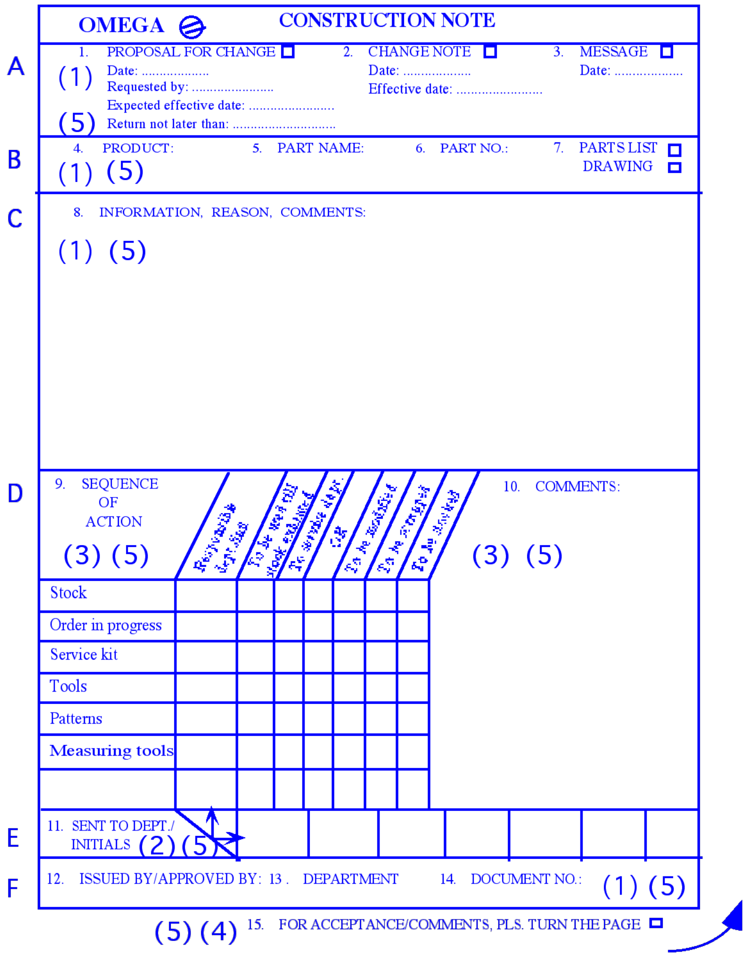

Figure 5: The change note version of the construction note form. The numbers in round brackets relate fields in the form to procedures for using the construction note mechanism.

3.2.1 Triggering conditions for the change note

CN1: There is a transition from CN1 to CN2. This transition is triggered by changes in the field of work for example changes in the company bill of materials or the acceptance of a proposal for change, i.e., the acceptance of a proposal for change also reflects an accept to change certain aspects of the field of work. The distinction between the two conditions is that information is available from the proposal from change and can be reused, while information regarding a change decided upon by an engineering designer is to be created from scratch. The responsible engineering designer fills in fields He/she decides which departments and responsible actors should engage in the further processing of the change. Using distribution lists he/she decides which recipient categories are relevant regarding the change in question. On the basis of negotiation with responsible actors from within these categories a sequence of action is determined and then stated in the form. The form is copied, archived and finally distributed to the actors in question. A change note is always send as a request to the responsible technical writer(s) in the technical documentation department.

CN2: See CN1

CN3: The different recipients archives the change note in local archives.

CN4: Two transitions are possible. The technical writers decide whether a change note is acceptable seen from their point of view on the basis of their special knowledge regarding the product in question and an investigation into the existing inventory of documents in the technical documentation archives. The transition CN4-CN5 is triggered if the change is rejected. Fields are filled in and information is added regarding the causes of rejection. The rejected change note is send back to the originator. The transition CN5-MN1 is triggered if the change is acceptable and a Modification Note is created.

CN5: See CN4

MN1: See CN4

CN6: Two transitions are possible. The responsible engineering designer will either accept the reject and alter fields and design of sequence of action according to the causes of rejection given by the technical writer(s) (transition CN6-CN2, see CN1) or accept and drop the change.

3.3 The message facility

The construction note message facility (figure 6) is used as an extension to the change note system. It is primarily used to give the people involved in the production of technical documentation detailed information regarding changes to materials, components, tools and bill of materials which has to do with the function, data, design and spare parts of product. The information is used as a basis for the production of modification notes.

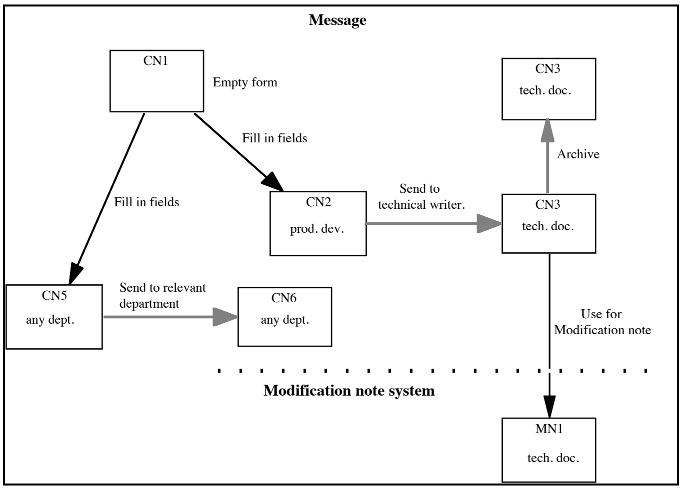

Figure 6: The message state transition diagram. Each box in the diagram illustrates the possible states of message part of the mechanism. Black arrows illustrate changes to the content of the mechanism, i.e., it is updated while gray arrows indicate the triggering condition for changing and updating the mechanism.

The general procedures using the message facility are:

(1) Technical information has to be distributed quickly in relation to an expected change and the creation of a change note, fields are filled in and technical information is attached to the construction note message.

(2) The information is distributed to relevant departments, which archive and use the information for changes in for example work plans. The technical documentation department uses the information as a basis for the creation of a Modification note.

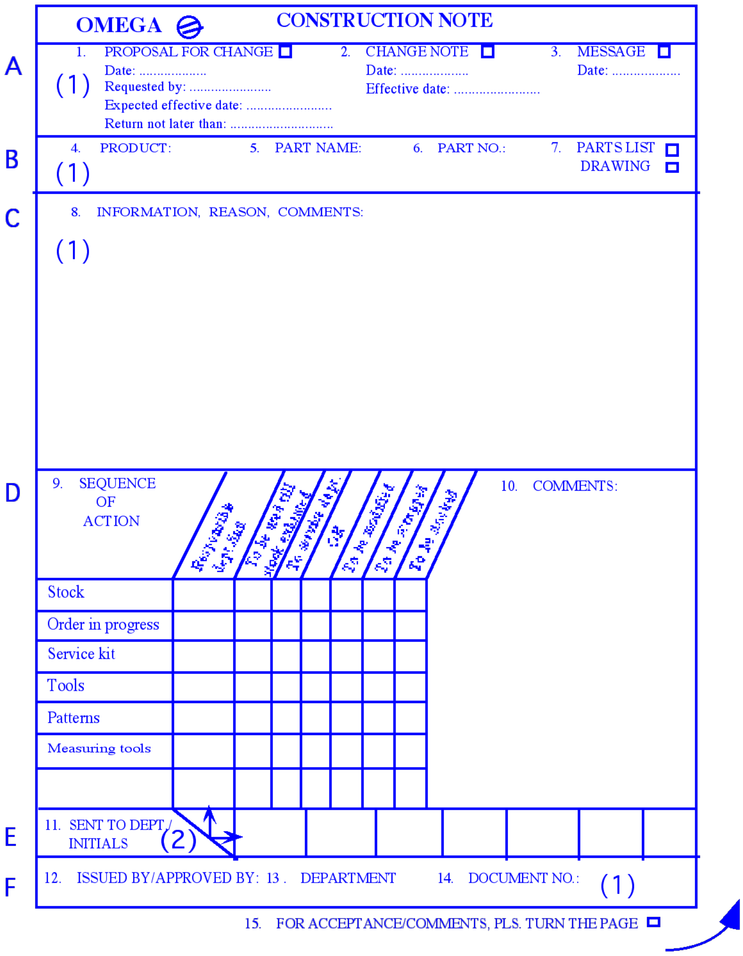

Figure 7: The message version of the construction note form. The numbers in round brackets relate fields in the form to procedures for using the mechanism.

3.3.1 Triggering conditions for the message facility

CN1: There is a transition from CN1 to CN2 and CN5. This transition is triggered by the need quickly to exchange or distribute rather informal information about changes to come. The difference between state CN2 and CN5 is that information, often in the form of a bill of materials and/or drawings, is attached n the CN2 state while this isn't the case regarding the CN5 state. The message in state CN2 is send to the responsible technical writer. The message in state CN5 is distributed to other relevant department on the basis of distribution list. The responsible people in these departments read and archive the message.

CN2: See CN1

CN3: There are transitions from CN3 to MN1 and CN3 to CN4. These transitions are triggered by the attached information objects. The technical writer archives the message and the attached information objects.

CN5: See CN1

4. The construction note objects and functions of articulation work

According to Schmidt et al., (1993) articulation work can be conceived of as “the overhead activities” needed in order to coordinate, mesh, allocate, etc., the so to speak “real” work activities. Furthermore the articulation work is carried out in relation to certain dimensions or objects, i.e., who, what, where, when, how, etc. These dimensions or objects refer to structures, processes, temporal and spatial aspects and agents in respect to work practices and settings. Moreover the objects are embedded in the social mechanism of interaction facilitating the articulation activities. The articulation work regarding these objects includes a set of elemental operations or functions. For example, an actor could reject or accept a task, or make someone else responsible for carrying out a certain task.

This section will discuss the objects of articulation work embedded in the construction note and the associated standard, conventions and distribution lists. In doing so we will take as a point of departure the list proposed by (Schmidt et al., 1993) containing possible candidates for objects of articulation work: Actors, responsibilities, tasks, activities, conceptual structures, and common resources in terms of information resources, material resources, technical resources and infrastructural resources. In this draft version of the paper a few of the objects are briefly discussed while others are just listed.

4.1 Actors

Many types of actors are involved in the process of propagating changes using the construction note, i.e., engineering designers, technical writers, product managers, tool designers, quality managers, construction engineers, marketing managers, service managers, production engineers, stock personnel, sales managers, in different departments and subsidiary companies around the world are involved in the articulation of changes in products, information objects, processes, prototypes, tools, etc. There are pointers to these actors in the “requested by”, “responsible dept./init”, “sent to dept./initials”, “issued by/approved by” fields (see figure 1, segments A;D;E;F)

Since focus in the field study was on the production of technical documentation only the role and professional background of the technical writers, and engineering designers will be mentioned here.

The engineering designers act both as mediators of proposals for change and as change managers. They assign people to do change related tasks on the basis of negotiation, they designate responsible people on the basis of distribution lists, they make requests regarding proposal for changes, they accept or reject proposal for changes on the basis of feed-back from relevant responsible people in the work arrangement.

The technical writers investigate and transform construction notes. They are allowed to produce proposal for changes and messages. They review and investigate change notes and proposal for changes. The investigation takes place in order to determine the consequences of the change in question of work processes other products and the information resources associated to these products. They reject or accept changes on the basis of the investigation. They are assigned to modify, scrap or stock technical documentation on the basis of change notes. They produce and distribute modification notes on the basis of changes and messages.

4.2 Responsibilities, tasks and activities

The overall activity regarding the construction note is to manage the propagation changes, i.e., to classify, control, monitor, coordinate, make publicly perceptible, make people aware of and negotiate the changes to products, parts, information objects, conceptual structures, etc. And furthermore allocate people either to carry out the needed tasks and sequences of action on the basis of the changes in question or to assign people the responsibility further to allocate resources for and mesh, monitor, coordinate, etc., change related tasks.

The articulation of responsibilities regarding tasks related to changes is delegated using the “sequence of action” field. The persons responsible is pointed at in the “responsible dept./init” fields. If pointed at in these fields people are designated control of sequences of action related to the task. This could be to modify or scrap for example inventories of materials, product parts technical documentation, etc. Also people are allocated responsibilities to assign, monitor and control tasks related to for example the use of specific materials, product parts, technical documentation, etc., that are part of service kits, tools, prototypes, product under order in progress and measuring tools till inventory is exhausted or they are allocated responsibilities to assign, monitor and control tasks related to modifying, scrapping or archiving this series of items. The persons responsible for the delegation of responsibilities monitor the process by using the construction note archives in order to specify what went wrong and who was responsible if a project failed to fulfill a certain milestone, couldn’t keep deadlines, or used to may resources.

Regarding the construction note itself the engineering designers are in charge of handling the change note and proposal for change processes. They archive construction notes and reject or accept proposals for change. They are responsible for the determination of sequences of action. The technical writers investigate implications of changes to other product variants. They can reject or accept changes note. They produce and distribute modification notes. The are allowed to make messages and proposal for change. Responsible people in other departments read and archive construction notes. They are allowed to make messages and proposal for change. Task related to the use of the construction note is as follows: Prioritize changes; report on changes; classify changes in order to send construction notes to relevant people; point out relevant people on the basis of classification of changes; refer and relate changes to objects in infrastructural resources; describe change (semi-structured messages); negotiate assignments of tasks and actions -- who is to do what when; copy and distribute construction notes (messages, change note and proposal for change); investigate consequences of changes; review construction notes; collect and attach data to messages.

4.3 Conceptual structures

Propagating changes in the field of work includes propagation of changes in conceptual structures. Changes to the company the product identification scheme is propagated using the construction note and sequences of action related to such changes are allocated different actors. The product identification scheme stipulates and mediates naming of product. It ensures that unique name identifiers are designated products. There is a pointer to the product key classification scheme in the "product field" (see figure 1, segment B). Another classification structure embedded in the form is the classification of changes. The classification of changes is partly stated in the procedure for the use of the construction note and relies partly on convention and "common sense". In delegating responsibilities, regarding sequences of action, a case sensitive distribution list is used, i.e., classes of changes point to the use specific distribution lists in distributing the construction note forms. A third conceptual structure referred to is the standardized technical terminology as it is objectified in the so called "work original" used in the company. The work original specifies, among other things, the terminology to be used in setting up semi-structured messages (see figure 1, segment C), i.e., it specifies correct and unique naming of unique product parts, service kits, tools, measuring tools, materials, etc. Both the engineering designers and the technical writers are engaged in the maintenance, standardization and refinement of the technical terminology expressed in the work original.

4.4 Information resources

The following is a list of information resources that contain information to be used in the work.

Parts list; (see figure 1, segment B) part name, part no, parts lists. The field is used to indicate if the change will have any effect on the parts list and the bill of materials. Also parts list and the bill of materials can be attached the construction note.

Distribution lists are used in distributing construction notes forms and in allocating responsibilities for sequences of action (see figure 1; segment D;E).

Drawings; (see figure 1, segment B) this field is used to indicate if the change will have any effect on CAD-models. Drawings can be attached the construction note.

Technical documentation is used in investigating consequences of change to other products that the one in question in a given construction note.

The standard for construction note used in filling in fields and setting up distribution lists according to classification of changes.

The organization handbook used as a basis for setting up distributing list according to classification of changes.

The project plan is used in deciding when a construction note is to be send out. It is used in relation to information stated in the construction note standard.

4.5 Material resources

The construction note has pointers to assemblies (service kits fields), prototypes (pattern fields), components (stock fields), process (order in progress fields), (see figure 1 segment D). The pointers link sequences of action to the material resources. They also link responsible actors to material resources. Assemblies, components and prototypes can be allocated, reserved, modified, scrapped, moved or used. A process can be maintained as it is, modified or scrapped.

4.6 Technical resources

The construction note has direct pointers to machining tools and measuring tools. The pointers link sequences of action to the technical resources. They also link responsible actors to technical resources. Machining and measuring tools can be maintained as they are, used, allocated, moved, modified, scrapped or reserved.

4.7 Infrastructural resources

As objects of articulation work infrastructural resources can be exemplified by rooms, buildings, communication and transportation facilities. There are no direct pointers to infrastructural resources in the construction note. There is though a reference to inventories (stocks) which are placed at different locations, the pointers to these locations are embedded in the semi-structured messages given.

4.8 Wider frames of reference

Besides the object of articulation work mentioned above articulation work has to be conceived of in the light of wider frame of reference. That is the demands and constraints posed by the work environment, the state of the field of work and the wider organizational setting. Furthermore articulation work is carried out with reference to time and space (Simone and Schmidt, 1993) .

4.81 The demands and constraints posed by the work environment

The demands and constraints posed by the work environments are illustrated in figure 8. These demands and constraints are mainly seen from the perspective of the different functions directly engaged in the production of technical documentation, i.e., the technical writers and the engineering designers.

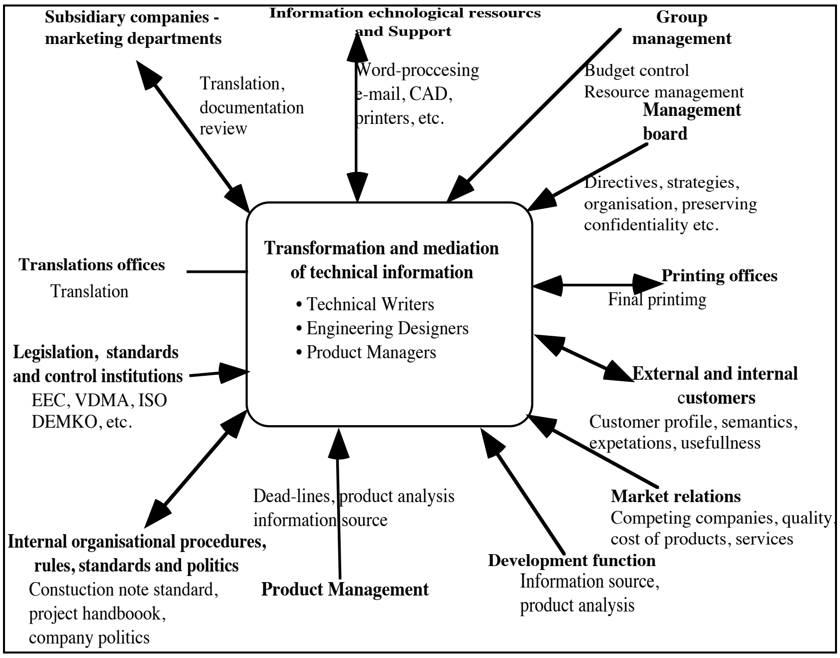

Figure 8: The constraints and demands of the work environment shown from the perspective of the production of technical documentation

The constraints and demands of the environment are mainly illustrated from the technical writers point of view. I will not go into any detailed discussion regarding the constraints and demands here, just make a couple of comments. The technical writers have incorporate changes in the different variants of technical documentation and keep the documentation up to date. When doing so they have to take into consideration the demands put on technical documentation from, for example, legislation, international standards, control institutions, etc. Also the need quickly to inform various internal customers like sales and service companies around the world is vital to keep the quality goals of the company. For the company as a whole it is necessary to control propagation of changes very carefully because of the size of the company, the number of product variants (approximately 25.000) and the number of subsidiary service and sales companies around the world. Also there are many parallel processes set ahead and they are running simultaneously.

4.8.2 The state of the field of work.

There are references to the state of the field of work in the sequence of action fields. The “order in progress” field is for example used to indicate whether or not and in case which action has to be taken regarding the products under order of progress, given a certain change. Also references are given using semi-structured messages in description fields. In general any change to products requires that information in several different technical documents has to be updated. Changes in products and components has to be reflected in the product classification scheme. The ongoing refinement and standardization of the technical terminology has to be reflected in the work original described above. The engineering designers have to take in consideration in what stage the product is, in its development phase, and determine the consequences in terms of changes in project plans, drawings, calculations, etc.

4.8.3 The wider organizational setting

The construction note is used to propagate and articulate changes horizontally and vertically in the organization. In this way it is not only distributed across organizational boundaries within the main company site but also between the main company site and the subsidiary companies around the world. References to the wider organizational setting are given in the “to service dept.”, “sent to dept./initials”, “responsible dept./init.” and “department” fields. Information in these fields is extracted from the so called organization handbook which is available both in an electronically and paper based version. The structure of the organization is stated in the organization handbook. That is who refers to whom, where are the actors placed in the organization hierarchy and in what organizational unit.

Employed in the company are about 8000 people spread around the world, of these are approximately 4000 people located at the main company site in Denmark. Around 250 people are involved in the engineering design. Nineteen persons are engaged in managing products. Twenty-five persons are involved in the production of technical documentation.

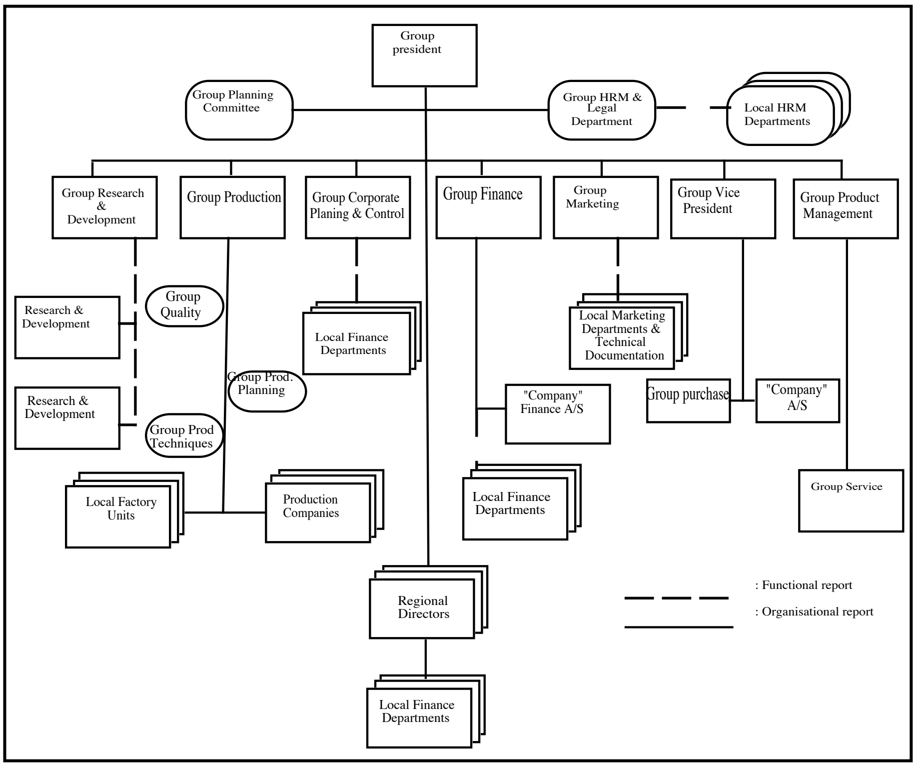

Figure 9: shows the organizational structure at Omega. The technical documentation department is placed in the Marketing Group together with the local marketing departments. The product development departments are placed in the Research and Development Group The product management departments are part of the Product Management Group.

The organization diagram is shown in figure 9. As seen the coordination between technical documentation department, the product management group and the development groups is at a rather high level in organization.

4.8.4 Time

The subsidiary companies are placed in several different time zones around the world. The change process typically runs for two to three months but can last several months more. Deadlines, milestones are specified in project plans. This has to be considered in relation to the propagation of change. Also specified production release dates and sale release dates have to be taken into consideration regarding the propagation of change. References are demanded in “date”, “expected effective date”, “return not later than” and “effective date” fields.

4.8.5 Space

The construction note has no direct references to space. All though there is a reference to inventories (stocks) which are placed at different locations, the pointers to these locations are embedded in the semi-structured messages given. The relation between space and the complexity of distributing the construction note could be worth mentioning. The construction note is used in the production, sales, service, technical documentation functions which are spread all over the world in 38 subsidiary companies. Three different company sites are located in Denmark. The main development, production and administration site cover a large area and are spread in many different buildings. The engineering designers, technical writers, tool designers, and product managers are placed far away from the production facilities. The technical writers, engineering designers, tool designers and product managers are placed in two buildings near to each other.

4.9 Summary of objects and functions of articulation work

The table in figure 10 summarizes the object and functions of articulation work described above. The first column illustrates the objects of articulation work in generic terms. The second column contains the concrete objects of articulation work embedded in the construction note and the associated standard, conventions and distribution lists. The third column contains the concrete elemental operations or functions related to the objects of articulation work referred to in the construction note.

Symbolic reference	**Symbolic reference in CN**	**Functions in CN**
Objects of articulation work		
Actors	engineering designer, technical writer, product manager, tool designer, service manager, quality manager, construction engineer, marketing manager, service manager, production engineer, stock personnel, sales manager;	assign;
Responsibilities	fields indicates which person has the overall responsibility carrying out or controlling the sequence of action;	allocate, accept, delegate, reject;
Tasks	scrap, modify and stock service kits, prototypes, tools, product under order of progress and measuring tools;	relate, point out, allocate, accomplish, prioritize, approve, dis-approve;
Activities	managing the change process.	monitor, make publicly perceptible, make aware of; questions;
Conceptual structures	technical terminology, classification of changes, product key classification scheme;	classify, relate, define, specify, exemplify relations between categories;
Technical resources	machining tools, measuring tools, prototypes (patterns);	maintain, use, scrap, modify; move, reserve, allocate;

Information resources	bill of materials, project plan, CAD-models, distribution lists, survey parts lists, technical documentation, company standards, the company project handbook, standard for construction note, organization handbook;	obtain, block, relate, attach, interpret, retrieve, locate, copy, scrutinize, report, compare, relate, transfer;
Material resources	materials, components, prototypes, products under order of progress assemblies (service kits);	modify, maintain, stock, use, scrap, allocate, reserve, move, place;
Infrastructural resources	none.	
External systems of reference		
Work environment	customers, standards, market relations, computer resources, communication facilities;	define, interpret;
Field of work	product stage in development phase, changes in classification of products and components, terminology changes, changes in release dates, changes in project plans	direct attention to, make sense of, monitor, act on ;
Organizational setting	many subsidiary companies, 8000 employees, 250 engineering designers, 25 involved in production of technical documentation, 19 involved in product management	navigate, define;
Space	38 subsidiary companies around the world, engineering designers and technical writers at different locations.	refer to coordinates in;
Time	date, effective date, expected effective date, return not later then, production time, order in progress	refer to point in;

Figure 10 Classification and characterization of the symbolic references and functions in the construction note.

As mentioned in chapter 2 the analysis of the construction note has been based on the concept of mechanisms of interaction as defined in Schmidt, (1993) . Also the table presented above in figure 10 is based on this definition. Findings in several empirical studies (found in part 1 of this book) based on the definition including the one reported here, has led to a refinement of both the definition and how to model the objects of articulation work and the elemental operations related to these objects. A detailed discussion of the refinement can be found in chapter 1 in COMIC Deliverable 3.3. As seen in figure 11 the list of objects and related operations, compared to the list in figure 10, now is divided along to axes. One major change is a distinction between the nominal and actual articulation work, i.e., a distinction between not yet realized and realized articulation work. Another change is the distinction between elements of the cooperative work arrangement and the processes of the field of work. The changes will not be further discussed in this paper.

Nominal		**Actual**	
Objects of articulation work	**Operations with respect to objects of articulation work**	**Objects of articulation work**	**Operations with respect to objects of articulation work**
Articulation work with respect to the cooperative work arrangement			
Role Engineering designer, technical writer, product manager, tool designer, service manager, quality manager, construction engineer, marketing manager, service manager, production engineer, stock manager, sales manager;	assign to [Committed actor]; responsible for [Task, Resource]	Committed actor	assume , accept, reject [Role]; initiate [Activity];
Task Scrap, modify and stock service kits, prototypes, tools, product under order of progress and measuring tools;	point out; relate; allocate, prioritize; accomplish, approve, disapprove; realized by [Activity];	Activity manage change process	[Committed actor]; initiates [Actor-in-action]; accomplishes; realizes [Task]; [Actor-in-action] makes publicly perceptible, monitors, is aware of; explains, questions;
Human resource • Smith • Jones • etc.	locate, allocate, reserve;	Actor-in-action	initiates [Activity]; does [Activity];
Articulation work with respect to the field of work			
Conceptual structures classification of changes, product key classification scheme, technical terminology;	categorize; define, relate, exemplify relations between categories pertaining to [Field of Work]	State of field of work product stage in development phase, changes in classification of products and components, terminology changes, changes in project plans;	classify aspects of [State of field of work]; monitor, direct attention to, make sense of, act on aspect of [State of field of work];

Informational resources bill of materials, project plan, CAD-models, distribution lists, survey parts lists, technical documentation, company standards, the company project handbook, standard for construction note, organization handbook;	locate, obtain access to block; access to;	Informational resources-in-use	copy to [Actor], move from [Actor], transfer; read, interpret, relate, retrieve; attach, scrutinize, report, compare
Material resources materials, components, prototypes, products under order of progress assemblies (service kits);	allocate, reserve;	Material resources-in-use	consume, modify, maintain, scrap, move from [Actor], place near [Actor]
Technical resources	allocate, reserve;	Technical resources-in-use	consume, modify, scrap, maintain, move, place;
Infrastructural resources	none	Infrastructural resources-in-use	none

Figure 11. The refined model of construction note objects and operations of articulation work.

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The bug report form

Peter Carstensen

Risø National Laboratory

Software testing is a demanding and difficult task involving many actors who needs to coordinate their activities, distribute and be aware of state of affairs information, negotiate the classification of errors, etc. To support the distributed nature of the testing activities different forms, schemes, etc. combined with procedures and conventions for how to handle the software errors (bugs) are often used. This paper reports, in a descriptive manner, from a field study conducted at Foss Electric. The field study addressed how software designers in a large project articulated their activities. An interesting finding was, that the software designers involved in the project realized problems in monitoring, coordinating, and handling the testing activities. To cope with the increasing complexity in these activities they invented and used a standardized bug registration form and a set of procedures and conventions for how to handle the process of registering, diagnosing, and correcting the bugs. In this paper we consider, analyze, and describe the bug form and the procedures and conventions as a Social Mechanism of Interaction

(Schmidt,

1993). The purpose is to establish an empirically based foundation for evaluating and improving the concept of mechanisms of interac-

tions (Schmidt et al.,

1993). Furthermore, the analysis improved our understanding of what characterizes the central activities in articulation work, and how articulation of software testing is supported and stipulated by means of forms and procedures.

1. Introduction

In large software development projects the testing of the software is a demanding and difficult task. It often requires and involves many actors who need to coordinate their activities, distribute information on identified errors (bugs), be aware of results from others' tests, negotiate on the classification of an error, etc.

This paper reports from a field study conducted at Foss Electric. The field study addressed how the software designers in a large project (the S4000 project) articulated their activities in the last stages of the project. The field study and central characteristics of Foss Electric and the S4000 project are described in details in a Appendix A of this book (Carstensen and Sørensen, 1994a).

An interesting observation in the field study was the use of what the designers called the "Bug Form" (or bug report form). The software designers involved in the S4000 project realized problems in coordinating, controlling, monitoring, and handling the testing activities. They invented and used a standardized form that all testers had to fill in whenever they identified an error (a bug). To prescribe the use of the forms a structured ring binder (being used as a central file) and a set of procedures and conventions for the use of the form was established. Some of these were written down as organizational procedures. Others were conventions developed during project.

The purpose of the form and the conventions and procedures was to 1) support a decentralized registration of bugs, 2) support a centralized decision making on how to overcome the identified problem, 3) support the correction activities in being handled in a decentralized manner, 4) provide an overview of the state of affairs (with respect to registered, corrected, verified, etc. bugs), both to the involved software designers and testers, and to the management of the software development, and 5) support a centralized process for verifying the implemented corrections.

This paper describes the form, the binder, and the procedures and conventions. We do this by means of the central aspects of the concept of mechanism of interactions (MoI) (Schmidt, 1993; Schmidt et al., 1993). We will consider the form, the binder, and the procedures as a social MoI. In the following these components are referred to as a whole by the term "the mechanism". Describing the mechanism by means of the concept of MoIs implies that the form and related procedures and conventions will be considered as a mechanism for "reducing the complexity of articulating distributed activities of large cooperative ensembles by *stipulating and mediating* the articulation of the distributed activities" (Schmidt et al., 1993, p. 110). It is thus relevant to discuss which functions related to articulation work the mechanism provide. By using the concept of MoIs certain characteristics of the mechanism becomes central: The mechanism is based on a publicly available and persistent artifact, the mechanism is symbolic and not coupled in any strong, tight, or irreversible way to the state of field of work, and the mechanism is based on a standardized format. Furthermore, the dimensions of "objects of articulation" along which the articulation work is conducted becomes essential. Objects of articulation are the references in the mechanism pointing to components and aspects in the field of work or in the cooperative work setting itself, e.g., references to actors, roles, tasks, conceptual structures, resources of different kinds, etc. (cf. Schmidt et al., 1993). The dimensions addressed in the mechanism are discussed in Section 5 of this paper.

It should be noticed, that the forms in the early stages of a software project often are used as a more informal mean for communicating ideas, suggestions, recognized problems, etc. Using the forms for this purpose is, of course, relevant, but it will not be explicitly addressed in this paper.

First the physical appearance of the form and the binder is described (Section 2). Then the use and function of the social MoI are described (Section 3). The conditions triggering new activities are important when describing a mechanism of interaction. The conditions for triggering new activities are discussed in Section 4. Section 5 describes the objects and functions of articulation work embedded in the mechanism. Finally Section 6 conclude the paper by a discussion of what we have learned through the analysis about the articulation of software testing, and the use of the concept of MoI.

2. The bug report form and the binder used

The mechanism uses two artifacts. First of all the bug report form. The form is a two pages form (both sides of one sheet of paper) used by all designers and testers involved in testing and developing the software for the S4000 instrument (cf. Appendix A or Borstrøm et al., 1994). It is filled in in several steps: partly by a tester recognizing a bug, partly by the spec-team diagnosing the problem, and partly by the designer correcting the bug. This will be described in further details in the following section. The description is structured by means of a state-transition diagram illustrating possible states of the mechanism, and by means of a non-formal description of the procedure, how the form is updated, how the routing between the activities is handled, etc.

As mentioned, the form is used by all actors involved in testing the software of the S4000 instrument. The sequence in which the fields are filled in is described in the next section.

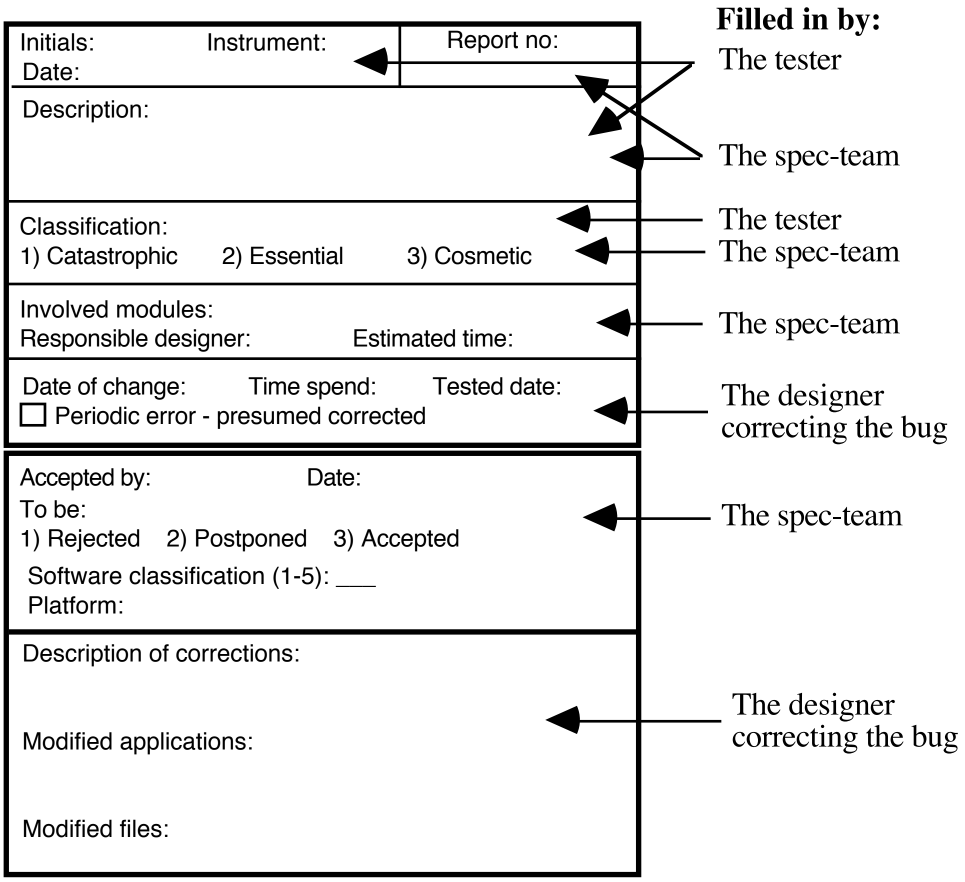

Figure 2-1: A translated version of the 2 pages bug report form. The right side of the figure illustrates which actors (roles) fills in the fields. The actors (roles) involved in software testing at Foss Electric are characterized in the beginning of Section 3.

One of the basic ideas in the mechanism is, that there should be exactly one (original) form filled in for each registered bug. The possession of the form is an implicit indication of the state of the bug (registered, diagnosed, corrected, or verified) In some stages of the registering, diagnosing, and correcting process a copy of the form is inserted in the central file (the binder) in order to keep an overview of the state of affairs.

The second artifact included (used) in the mechanism is a ring binder containing all forms (either the original or a copy) filled in and diagnosed by the spec-team (i.e., all registered bugs). This binder is physically placed in the same room as all the actors involved in developing the S4000 instrument, i.e., the binder is easily accessible to all the software designers engaged in the project. Some of the involved testers are also engaged in the project as software, hardware, or mechanical designers, i.e., they are placed in the same room as the software designers and the binder. Other testers are employed in other departments (e.g., the marketing department) and have thus not as easy access to the binder.

The purpose of the binder is to provide awareness of the state of affairs in the testing of the instrument to all involved designers and testers. Furthermore the binder is used by the management to get an overview of the state of affairs and the progress in the project. The binder is maintained by one of software designers engaged in the project. He does this in close interaction with other software designers, especially with the actor having the role as platform master (cf. Borstrøm et al., 1994). This will be described further in next section.

The binder has seven entries (Figure 2-2). In each of these entries the forms are inserted and organized in a chronological order.

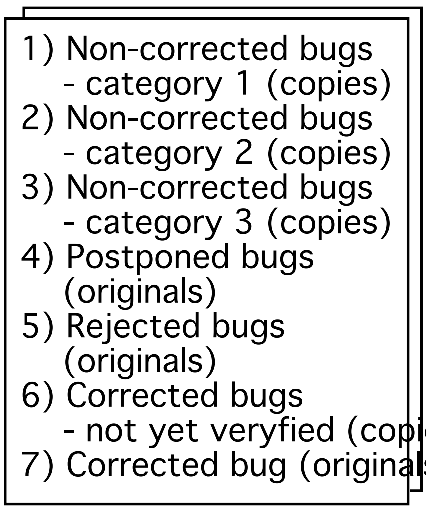

Figure 2-2: The seven entries used for filing the bug report forms. The headings for the entries are translations of the table of contents in the original binder.

The use, maintenance, etc. of the binder will appear from the descriptions in the following sections.

3. The use of the mechanism

This section describes in further detail how the mechanism is used. First step in the description is made by means of a state-transition diagram (Figure 3-1) illustrating the possible states of the mechanism and the possible transitions from one state to the other. Next step is a procedure oriented description of the overall procedure used when the mechanism is running. In the end of the section a short subsection illustrates the use of the mechanism seen from the point of view of the involved actors.

As mentioned earlier several (groups of) actors are involved in the articulation of the software testing. Before starting the description it is relevant to describe the groups of actors involved in testing the software and thus in using the mechanism. These are:

(1) The testers.

Testers are the actors involved in the concrete testing of the software embedded in the S4000 instrument. The testers can be affiliated in several different departments at Foss Electric. They have thus a very different background and approach to what functionality the software must provide, and what the most important characteristics of the software are (e.g., usability, stability, correctness, maintainability, etc.). They are typically software, hardware, or mechanical designers involved in the project, or they are employed in the departments of quality assurance, marketing, service, maintenance, etc.

(2) The spec-team.

This is a group of (for the present) three software designers responsible for diagnosing the bugs and deciding how to handle each of the bugs. The members of the spec-team in the S4000 project are appointed so that all the three main "layers" in the software are represented: One has deep knowledge on aspects regarding the user interface and the used file structures, etc. One has deep knowledge of the algorithms used for computing the measuring results. And one is very experienced in developing software interfacing to the network, the hardware, and the external devices controlled by the software.

(3) The software designers.

All software designers are responsible for one or more software modules. Hence, when a bug is diagnosed and related to a specific module the designer responsible for correcting the bug and report back is "automatically" assigned too.

(4) The central file manager.

At any given point in time of the S4000 project, one of the software designers is responsible for organizing and maintaining the central file, the ring binder. Ahead of each integration period the central file manager is responsible for informing the platform master on which corrections have to be verified in the integration, i.e., inform the platform master on which bugs have been reported as corrected since the previous platform integration period.

(5) The platform master

The platform master is one of the designers in the project. He is responsible for managing and coordinating all the activities involved in the integration period. He is, among other things, responsible for verifying the corrections made by the designers. The software designers involved in the project alternately take the role as platform master.

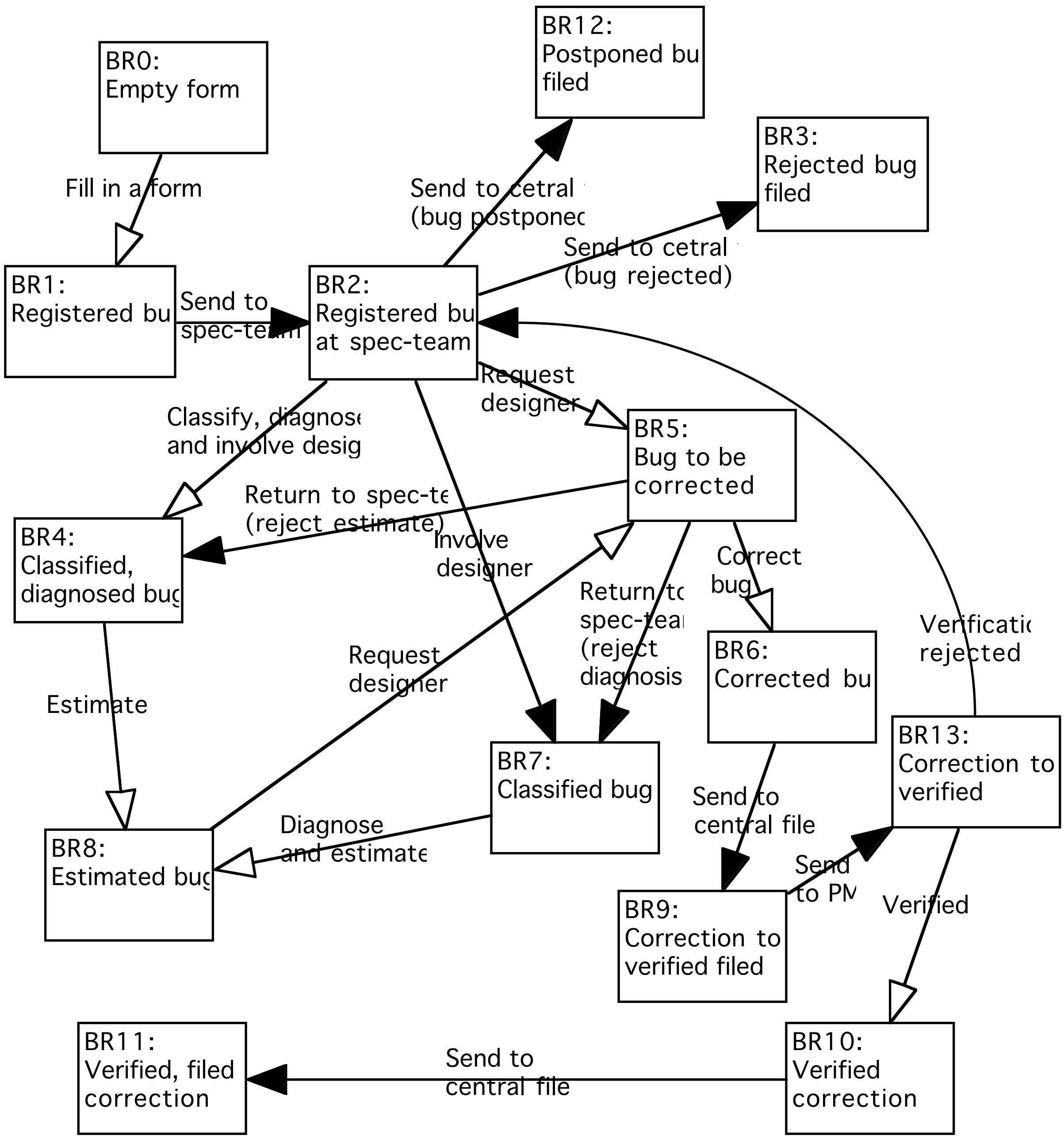

Figure 3-1: A state-transition diagram of the social mechanism of interaction described in this paper. The purpose of the mechanism is to support the articulation of the software testing work in the S4000 project. Each box illustrates a possible state the mechanism. The arrows illustrate possible actions (transitions) that can be taken. Each arrow points at the new state a given action will result in. Arrows with a white head reflects an action that makes changes to the content of the mechanism; here mainly in terms of adding new information to the form. Arrows with black heads reflect changes in who is in control of the mechanism, i.e., allowed to change the state of the mechanism.

The state-transition model illustrated above reflects the possible different states of the mechanism, and the possible next “legal” steps. It can thus be regarded as a model of the mechanism itself, i.e., a model of the states of the articulation of the testing activities. It is not a model of the states, procedural steps, or of the activities involved in the testing work itself. Neither is it a model reflecting the different actors involved in work.

3.1 A procedural description of the mechanism

The overall procedure for how the mechanisms works and the how the forms and the binder are updated is illustrated in Figure 3-2 below.

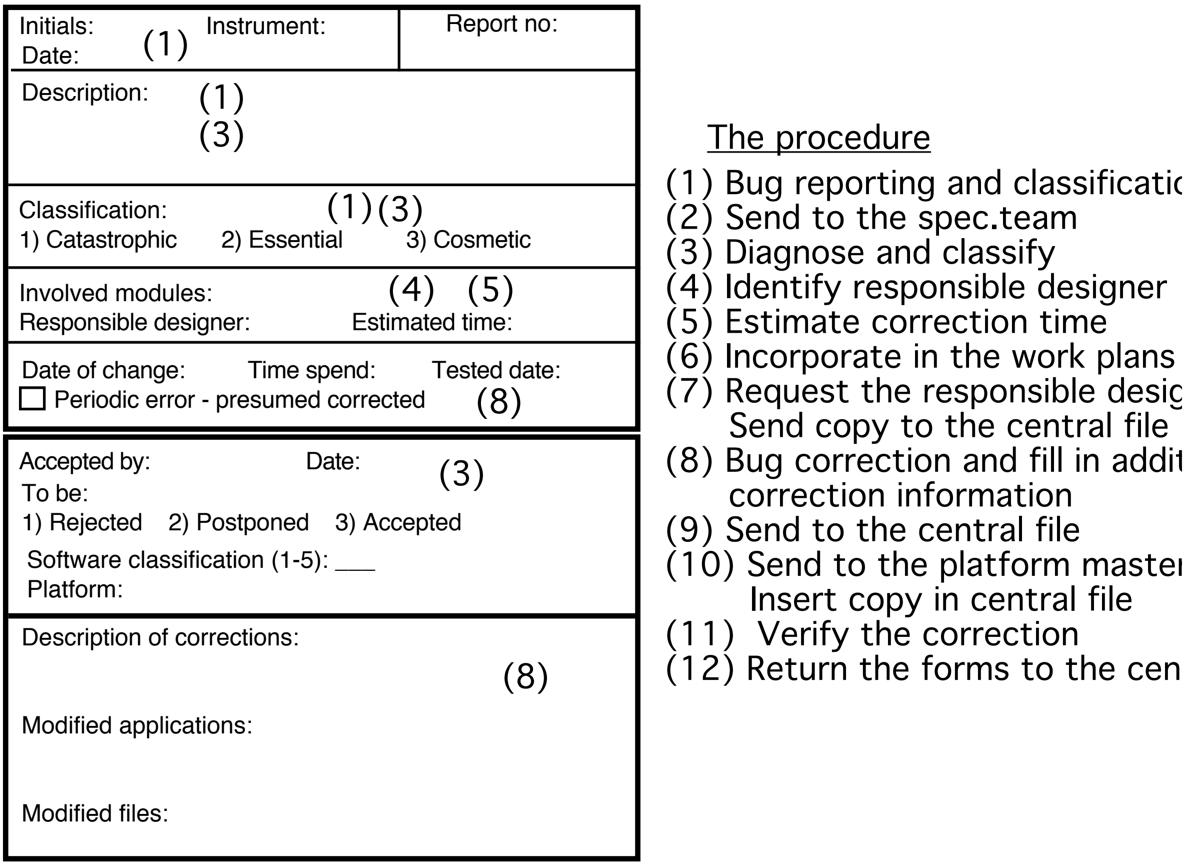

Figure 3-2: The bug report form and a 12 steps overall procedure for the use of the mechanism. The numbers in the form illustrate in which step of the procedure the field is affected.

The overall procedural steps are:

(1) A bug is recognized by a tester. He fills in a form and classifies the bug.
(2) The tester sends the form to the spec-team.
(3) The bug is re-classified and diagnosed by the spec-team.
(4) The responsible module/designer is identified by the spec-team.
(5) The correction time is estimated by the spec-team.
(6) The required correction tasks are incorporated in the work plans. This is done by one of the member of the spec-team.

(7) The spec-team sends the form (the original) to the responsible designer. This can be regarded as a correction request. The spec-team sends a copy of the form to the central file (the binder).
(8) The bug is corrected and additional correction information is filled in on the form by the responsible designer.
(9) The responsible designer sends the form to the central file.
(10) The central file manager inserts a copy of the form in the central file, and sends the form (the original) to the platform master.
(11) The correction is verified by the platform master.
(12) The accepted forms are returned to the central file manager.

Each step in the procedure is described in further detail in the following. The activities will be related to the use of the forms and the binder. The descriptions will be related to the different states and transitions in the diagram in Figure 3-1.

Most of the concrete cases are handled according to the prescribed procedures. In some cases an actor might, however, choose to deviate from the procedure, e.g., if a tester knows who is responsible for a specific bug he can contact the designer without involving the spec-team. Some of these deviations are characterized in the following. The description will, however, not attempt to describe all possible situations. It is considered impossible to predict all possible situations.

3.1.1 Bug reporting

When a bug is identified by one of the involved testers a new form is filled in. The intention is, that the tester fills in a form for each bug he identifies. It might, of course, be difficult to decide if a problem is "the same" as one that where identified earlier or to see if a concrete problem actually is caused by several different software bugs.

The tester fills in his initials, the date, an identification of the instrument and the software version he has used, and he describes what he did and how the instrument reacted. Finally he fills in a classification (catastrophic, essential, or cosmetic) of the importance of the problem. Filling in the information is reflected in the state-transition diagram (Figure 3-1) as the transition from state BR0 to state BR1.

An exception to the described procedure is that the tester personally contacts one of the members of the spec-team (or one of the other software designers), and verbally reports on the problem. In this case the spec-team member or designer will, if the problem is considered relevant, fill in a form.

3.1.2 Send the form to the spec-team

Having filled in a new form the tester sends the form to the spec-team. This is illustrated in the state-transition diagram as the transition from BR1 to BR2. Usually this is done by use of the internal mail.

There are at least two exceptions to this procedure step. If the tester consider the identified problem as being very important (having classified it as catastrophic) and he decides that the diagnose and correction of the problem cannot be delayed further he might contact one of the members of the spec-team and discuss it with him immediately. If the tester knows who is probably going to be responsible for correcting the bug he might choose to personally contact the designer and discuss the problem with him before sending or handing in the form to the spec-team.

3.1.3 Diagnosing the bug

This section describes what is illustrated as three steps in the procedure in Figure 3-2, namely the diagnose and classification of the bug (step 3), the identification of the responsible designer (step 4), and the estimation of the expected correction time (step 5). All these steps are handled by the spec-team and is usually conducted concurrently and intertwined. The spec-team will typically have a meeting ones a week. In periods with very intensive testing activities it might be more frequent.

The spec-team starts the by checking if any of the incoming bugs are identical. This is done by comparing the description of the incoming forms. If two registered bugs are considered identical only one of the forms is treated.

For each form the spec-team decides if the described bug can be accepted as a bug. If not the form is classified as rejected and the form is send to the central file manager (the transition from BR2 to BR3) who inserts it into the "Rejected bugs" entry (cf. Figure 2-2). The next step is to decide whether the bug is important or it can be postponed. If the bug is postponed the form is classified as postponed and the form is send to the central file manager (the transition from BR2 to BR12). The central file manager files the form in the binder in the "Postponed bugs" entry (cf. Figure 2-2).

The remaining forms are classified as accepted. Then they are classified according to importance. This is done by use of two classification structures on the form. First the classification made by the tester is corrected (re-classified). Usually the classification is not changed, but if the spec-team disagrees in the classification they might change it. If there is a deviation in the tester classification (and description) and the spec-team classification, the spec-team might choose to contact the tester and negotiate the classification.

The importance is filled in the field for "Software classification". This field is at the same time an indication of in which of the next platform periods the bug should be corrected. The development and test work are organized in platform period working cycles (or working rhythms)[47].

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47 A platform period was typically 3–6 weeks work followed by one week of integration. All the work and the plans were structured in relation to these periods. The platform master was responsible for collecting all information on updates and changes made to the software, and for ensuring that software was tested and corrected. All the other developers were not allowed to develop the software further before the "platform" was released and a new development period could be started. The work can thus

If the diagnose and the estimation of time required to correct the bug is fairly simple, the spec-team fills in (writes) the diagnose in the "Description" field of the form, fills in the "Involved modules" field, the "Estimated time" field the, and the "Responsible designer" field. The responsibility is distributed (i.e., all modules have one software designer associated). Hence, the decision of, who is responsible, is based upon which modules are considered involved. In cases where the diagnosis and time estimation are simple the spec-team incorporate the correction work in the plans (cf. Section 3.1.4) and sends a request (the form) to the designer (BR2 to BR5), cf. Section 3.1.5.

If the diagnose is complicated the spec-team can choose to call in the designer responsible for the relevant modules (BR2 to BR7). Then the designer is involved in diagnosing the problem and estimating the correction time (the transition from BR7 to BR8). When the relevant decisions have been taken the spec-team incor-

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be regarded as being organized in cycles or rhythms. For a more thorough description and discussion of this see Borstrøm et al. (1994).

porates the correction work in the plans (cf. Section 3.1.4) and sends a request (the form) to the designer (BR8 to BR5), cf. Section 3.1.5.

It might be that only the estimation requires involvement of the responsible designer. In these cases the spec-team fills in the “Description” field of the form, the “Involved modules” field, and the “Responsible designer” field (BR2 to BR4). The spec-team and the responsible designer cooperates on deciding the required corrections time (BR4 to BR8). As for the previous situations, the spec-team incorporates the correction work in the plans (cf. Section 3.1.4) and sends a request (the form) to the designer (BR8 to BR5), cf. Section 3.1.5.

The diagnosing and estimating work itself usually are a very complicated task requiring involvement of experts in different fields, use of the software specifications, source code, and documentation, etc. To describe this in further detail is, however, out of the scope of this paper.

3.1.4 Incorporate in work plans

The fact that a bug has been identified, diagnosed, and estimated results in a new task that has to be accomplished. The spec-team requests the designer or manager responsible for the overall project plan to include the new task in the plans. In the S4000 project the person responsible for the overall plan was identical to one of the spec-team members. Information on the task, the responsible designer, the estimated time, and the platform period are incorporated in the plans by the actor responsible for the overall project plan.

Since the plans are considered outside of the mechanism described in this paper the incorporation does not affect the mechanism. No transitions are thus triggered. Rather it can be seen as an example of a connection between two different mechanisms supporting the articulation of software development and testing: The mechanism supporting the distributed nature of the software testing discussed here, and another mechanism supporting the scheduling and allocation of tasks and human resources. A thorough discussion of linking between mechanisms of interaction is given both in a paper in COMIC Deliverable 1.2 (Schmidt et al., 1994) and in COMIC Deliverable 3.3 (Carstensen and Sørensen, 1994b).

A possible exception to the incorporation in the work plans is when the problem is corrected immediately by a designer or a member of the spec-team. Then the task will never occur in the plans.

3.1.5 Send request to responsible designer

The updated form containing information on the problem, the classification, the diagnose, the involved modules, and the estimated correction time is sent to the responsible designer. The designer should consider the form as a request. The request requires either that the bug is corrected, or the request is rejected (by contacting a spec-team member).

A copy of the form is send from the spec-team to the central file manager. The central file manager inserts the copy in the binder according to the classification on the form (cf. Figure 2-2), i.e., in one of the first three entries: “Non-corrected category 1”, “Non-corrected category 2”, or “Non-corrected category 3”.

If the spec-team has done all the diagnose and estimation work without involving other software designers sending the request is reflected in the diagram as the transition from BR2 to BR5. Otherwise the action is reflected in the state-transition diagram as BR8 to BR5.

An exception is, of course, that one or several of the members of the spec-team personally hand over the form to the designer and/or to the central file manager. This might be done just because it is the easiest way to do it, or it might be caused by the need for additional information, or if it is considered important that the correction work is launched immediately.

3.1.6 Correct the bug

Having received a form the designer controls if the diagnose, the estimate, and the deadline (the platform period) are acceptable. If the designer consider the estimate as to optimistic (low) he returns the form to, or personally contact, a spec-team member with a note stating, that the estimate is unacceptable (the transition from BR5 to BR4). The estimate is thus negotiated with the spec-team.

The designer might also disagree in the diagnose or in the descriptions of which modules are involved, i.e., he might disagree in what is the problem and/or who is responsible. In this case he will return the form to the spec-team with a note stating what is the problem in the diagnose (BR5 to BR7). The diagnose and the estimate will then be negotiated with the spec-team.

If the designer accepts the diagnose and believes he can handle the problem within the estimated resources and deadlines he corrects the bug. That might, of course, be done at a much later point in time.

Having corrected the bug, and tested the corrections, the designer fills in the fields of “Date of change”, “Time spend”, “Tested date”, and if relevant tip of the “Periodic error” field on the form. Furthermore, he describes the corrections made, and the applications (or modules) and files affected in the software complex. The addition of information to the form is reflected in the BR5 to BR6 transition in the state-transition diagram.

Finding the source to a bug and correcting it is a complicated task that requires intense studies of the source code and specifications, discussion with other designers, etc. Describing the character of this is out of the scope of this paper.

3.1.7 Send the form to central file

When the corrections are implemented in the code and information is added to the form the designer sends the form to the central file manager. The central file manager is responsible for maintaining the ring binder. He removes the old copy of the form (placed in one of the first three entries, cf. Figure 2-2) from the binder and throw it away. A copy of the updated (received) form (containing the additional information regarding the corrections) is filed in the binder in entry 6 “Corrected bugs to be verified” (BR6 to BR13).

3.1.8 Send the formto platform master

The central file manager sends the form (the original) to the platform master, illustrated as BR13 to BR9 in Figure 3-1. The platform master is responsible for the next platform integration period. The platform master is supposed to regard the form as a request for verifying the described corrections in the next platform integration period. There might be situations where the platform master decides to reject such a request, but we do not have any empirical material indicating that this can happen and how it is handled. If such a situation occurs it will probably result in a situation similar to the one described as the “correction cannot be verified” described in the following section.

3.1.9 Verify the corrections

During the platform integration periods the platform master is responsible for verifying the corrected bugs, i.e., control that each bug is corrected sufficient without introducing new problems. This can be done either by the platform master himself, or he can delegate the responsibility for doing this to other software designers. The verification is usually a complex and demanding task that is out of the scope to describe in this paper.

If the verification process results in an acceptance of the correction the form is placed in a pile of accepted forms (the transition from BR9 to BR10).

If the verification process results in a rejection of the correction one of several things can happen: The platform master can, if it is a minor problem, either correct the code himself or ask the responsible designer to do this immediately. If this is possible the form can be piled in the accepted forms pile (transition BR9 to BR10). If the correction of the bug can be verified, but it has introduced a new bug (or several) then the form is piled as verified (transition BR9 to BR10) and a new empty form is filled in describing the new bug (the transition from BR0 to BR1). Finally, if the correction cannot be verified the platform master can add a note in the “Description field” indicating the problems and send the form to the spec-team (BR9 to BR2).

A possible exception to the last mentioned procedure is that the platform master instead of sending the form to the spec-team returns the form to the responsible designer. This requires that the platform master ensures that a copy of the form is inserted in the relevant non-corrected bugs entry in the central file (done by contacting the central file manager). Furthermore, it requires that the platform master ensures that the work plans are updated (cf. Section 3.1.4).

3.1.10 Return the accepted forms to central file

Finally the forms piled in the accepted forms pile are send from the platform master to the central file manager. The central file manager removes all the copies of forms placed in entry 6 “Corrected bugs not yet verified” of the binder. The forms (the originals) received from the platform master are inserted in the “Corrected bugs” entry of the binder (the transition from BR10 to BR11 in the state-transition diagram).

The central file manager can check if the copies taken out are identical to the inserted ones. Forms that are removed, without having one with the same number inserted indicates corrections that could not be verified. The correctness of this can then be checked by comparing with forms in the non-corrected bugs entry. The procedures do not specify anything about this. Our study indicated that whether this check was made or not was depending on who was responsible for the central file.

3.2 The flow of the mechanism in an actors perspective

In the previous sections the procedure and process have been described with two different approaches: First from the perspective of the state of the mechanism, i.e., in terms of possible states of the mechanism and possible transitions that can be triggered, and second with a procedure oriented approach, i.e., describing the overall steps that are carried out while the mechanism is running.

A third obvious approach is to address the mechanism from the perspective of the involved actors, i.e., to focus on the information flow from the view point of the involved actors (or rather their roles). Figure 3-3 below illustrates the actors (roles) involved in articulating the testing activities in the S4000 project.

As mentioned in the beginning of section 3 there are basically five different roles involved in articulating the testing activities in the S4000 project. These are the testers testing the software, the spec-team diagnosing the bugs, the software designers correcting the bugs, the platform master verifying the corrected bugs, and the central file manager maintaining the central file in order to keep track of the state of affairs.

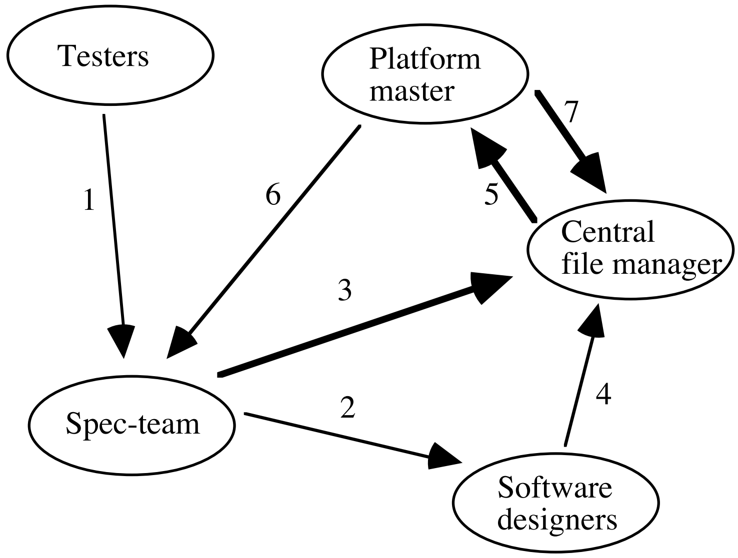

Figure 3-3: A visualization of the actors (roles) involved in the software testing of the S4000 project, and the information flow between them. The information flow described in the figure concerns only the stipulated (through organizational procedures) flow of the mechanism (the social mechanism of interaction described in this paper). The thick arrows (3, 5, 7) indicate that the flow is often a bunch of forms sent. The thin arrows indicates that the forms typically are send one at the time. Other types of information are frequently exchanged between the actors and there might be situations were one of the actors choose not to follow the stipulated information flow. Furthermore, it should be noticed, that the actors illustrated in the figure should rather be interpreted as roles. For example testers and responsible designers are named actors (although one could consider this as roles too), whereas platform master and central file manager are roles that the involved actors take turns at.

The general flow of information (route of the forms) follows the seven major steps illustrated in the figure:

(1) The testers send forms describing recognized bugs to the spec-team.

(2) The spec-team adds diagnose and estimation information to the form and sends it, as a request, to the software designers.

(3) The spec-team sends rejected forms and copies of accepted forms to the central file manager.

(4) The software designers add correction information to the form and sends it to the central file manager.

(5) The central file manager sends a pile of forms containing correction information to the platform master.

(6) Forms containing corrections that cannot be verified are send from the platform master to the spec-team which then recycle them in the process (starting from flow 2).

(7) Forms containing corrections that can be verified are send from the platform master to the central file manager.

4. The triggering conditions implemented

A mechanisms of interaction can be considered as a mechanism containing information required for handling the articulation activities, and having two channels. One channel is an ingoing channel used for updating or monitoring the content of the mechanism, i.e., update or monitor the state of affairs in the field of work. The second channel is an outgoing trigger channel. This outgoing trigger will, when certain conditions are fulfilled, trigger a series of tasks (or flows of work) to be activated (cf. Simone et al., 1994).

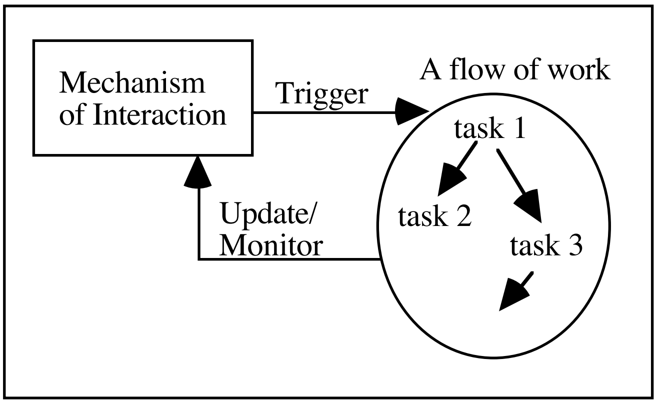

Figure 4-1: A simple model of a mechanism of interaction regarded as a mechanism with two channels. One used for updating and monitoring the content of the mechanism, and one used to trigger actions in the work that are articulated.

This section will, in some detail, discuss what can affect shifts (transitions) in the state of the mechanism; i.e., discuss what conditions, changes in the context, decisions taken by the actors, etc. are required in order to trigger a shift in the state of the mechanism. Such changes can be affected both by events in the outside world, and changes in the state of affairs in the field of work or in the cooperative work arrangement.

The changes are illustrated as transitions in the state-transition diagram of the mechanism (cf. Figure 3-1). We will go through the states the state-transition diagram one by one, and discuss what triggers a transition, i.e., what will affect or cause a shift in the state of the mechanism. In most cases shifts in state of the mechanism are caused by decisions taken by one of the involved actors, or caused by events in the context in which the mechanism functions. This will be discussed in the following.

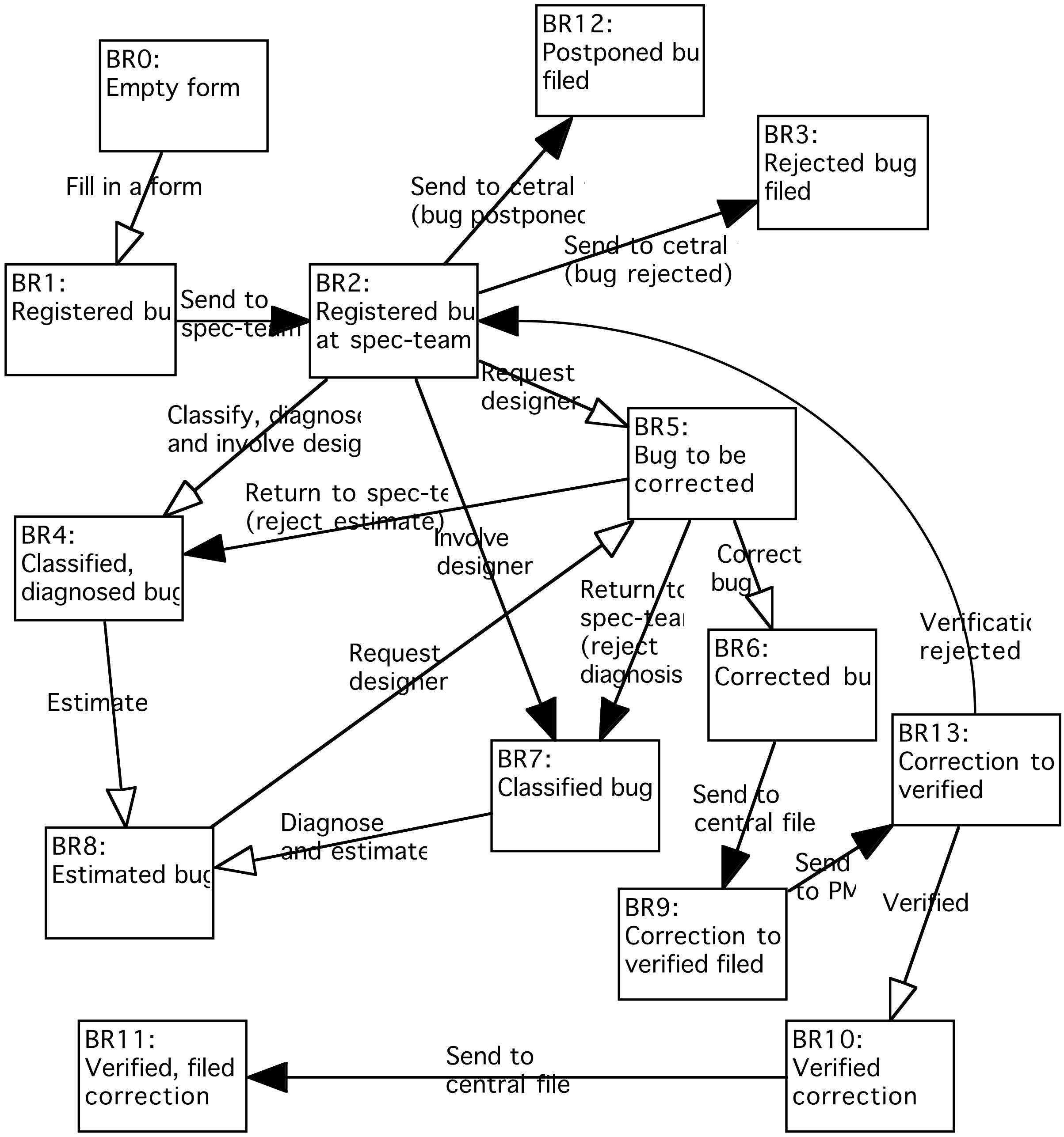

Figure 4-2: To facilitate the description in the following, the state-transition diagram supporting the articulation of the software testing work in the S4000 project is illustrated again. The figure is identical to figure 3-1.

The triggering conditions are discussed in the list below, one state at a time. Final states (i.e., states with no outgoing transitions) are not included in the list.

BR0: The only transition is the BR0 to BR1. This is triggered by an event in the work: a tester decides to categorize a problem in the software as a bug. To follow the procedures he must fill in a form and send this to the spec-team.

BR1: See BR0.

BR2: Here are a number of possible transitions. All transitions are triggered by decisions taken by the spec-team and related to the reported bug:

- BR2-BR12 if the correction is postponed,
- BR2-BR3 if the bug is rejected,
- BR2-BR4 if the estimation cannot be done without involving the responsible designer,
- BR2-BR7 if the diagnosing requires involvement of other designers,
- BR2-BR5 if no involvement is required.

Since the spec-team typically have meetings ones a week we can say that the decisions made by the spec-team are indirectly triggered by an external event: the occurrence of a specific point in time. The decisions taken by the spec-team can also be regarded as being implicitly influenced by another external source. All decisions taken by the spec-team are taken under influence of the constraints and policies directed from the management of the company. A classification will, for example, be closely related to the general product acceptance criteria and the time left before the product has to be released.

BR4: The BR4-BR8, BR7-BR8, and the BR8-BR5 are all triggered by decisions taken by the spec-team regarding the classification, the diagnose, or the estimation (cf. previous bullet). They are triggered by the information added to the form. Furthermore, they are triggered by a decision taken by the spec-team stating that the information in the form is sufficient for the responsible designer.

BR5: All possible transitions from BR5 depend on decisions taken by the responsible designer: If the diagnose cannot be accepted transition BR5-BR7 is triggered. Rejection of the suggested estimate triggers the BR5-BR4. Acceptance of the diagnose and correction of the bug (including addition of correction information to the form) triggers BR5-BR6. As for BR2 the decisions are influenced by the outside world since all decisions are taken within the constraints defined by the general policies.

BR6: BR6-BR9 is triggered when the responsible designer decides to send the form with correction information to the central file manager, i.e., the designer decides that the problem (the bug) has been solved.

BR7: See BR4.

BR8: See BR4.

BR9: The transition from BR9 to BR13 is triggered when the central file manager decides to send a pile of forms describing corrections to be verified to the platform master. This decision is related to an external event: the occurrence of a certain point in time. The organizational procedures state, that the central file manager must send the forms to be verified to the platform master two days before the next integration period is going to start.

BR10: When the platform master verifies the corrections he decides on the acceptance of the correction. If a correction is acceptable he staple the form (BR13-BR10), and when all forms are controlled he sends the accepted forms to the central file manager (BR10-BR11).

BR13: The platform master decides on the acceptability of the corrections. If it is okay see BR10. If the verification is rejected BR13-BR2 is triggered.

As it can be seen from the descriptions above, all the transitions (shifts in state of the mechanism) are triggered by decisions taken and actions made by the involved actors. Some of these actions have a second order triggering condition related to the occurrence of a specific point in time. Apart from these time related events and that external policies, etc. influences the decision making, none of the triggering situations are directly related to the outside world.

5. Objects of articulation reflected in the mechanism

A mechanism of interaction contains information structures relevant for articulating the work and for watching over the state of affairs. We have earlier called these structures "objects of articulation work" (Schmidt et al., 1993). Objects of articulation reflects (points at) structures in the actual field of work, the current cooperative work arrangement, and the context or outer environment in which the work is conducted (cf. Carstensen and Schmidt, 1993; Schmidt et al., 1993). This section will discuss which objects of articulation the bug report form mechanism handles, i.e., which structures in the field of work and in the work setting the mechanism reflects.

If we consider objects of articulation as the conceptualizations of work the actor uses when articulating the work, an important aspect of articulation work is to make "manipulations" (or operations) on these conceptual structures. In the end of this section a table illustrates the central objects of articulation reflected in the mechanism, and the basic functions (operations) used on the objects of articulations.

In a previous paper (Carstensen et al., 1994) we have identified the basic structures accessed and functions fulfilled when articulating software testing. These are illustrated in figure 5-1 below.

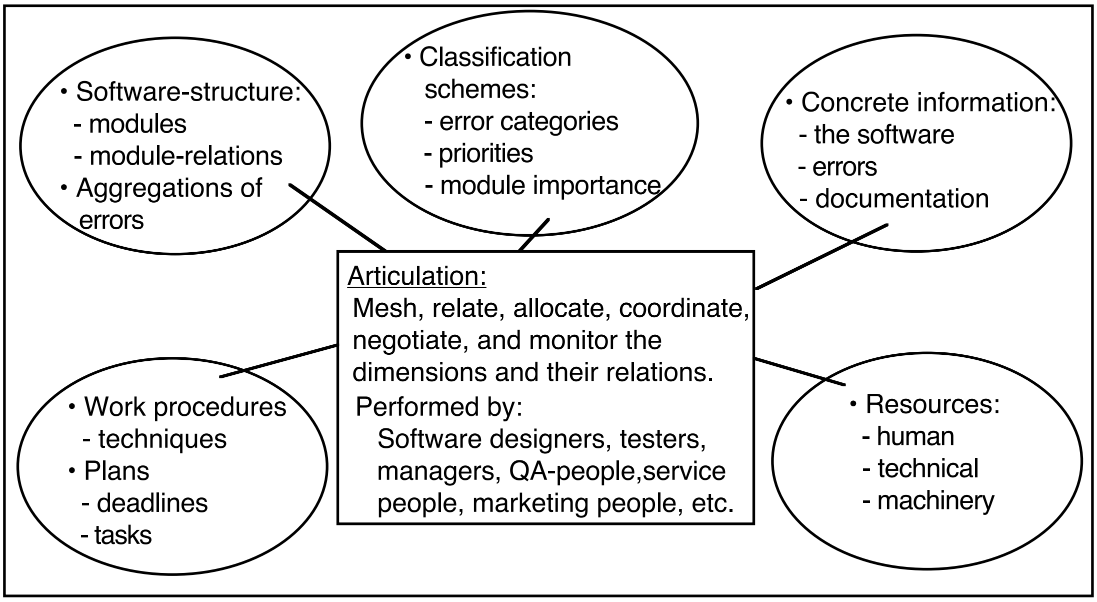
• Software-structure:
- modules
- module-relations
• Aggregations of errors
• Classification schemes:
- error categories
- priorities
- module importance
• Concrete information:
- the software
- errors
- documentation
Articulation:
Mesh, relate, allocate, coordinate, negotiate, and monitor the dimensions and their relations.
Performed by:
Software designers, testers, managers, QA-people,service people, marketing people, etc.
• Work procedures
- techniques
• Plans
- deadlines
- tasks
• Resources:
- human
- technical
- machinery

Figure 5-1: A graphic model of the articulation of the software testing process adapted from Carstensen et al. (1994). The circles illustrates the dimensions of objects of articulation (the conceptual structures) along which the work is articulated. The box contains the main functions to be fulfilled. The structures in the upper circles are mainly derived from the nature of the software testing work domain (the field of work), whereas the structures in the circles at the bottom mainly reflects the nature of the chosen organization of the work (the cooperative work arrangement). Neither the list of the conceptual structures or of the basic functions should be seen as exhaustive lists.

The structures in Figure 5-1 reflect what we have identified as the important structures used when articulating software testing.

The rest of this section concentrates on the structures reflected in the mechanism. For structuring purposes will we use the overall dimensions of objects of articulation we identified in Schmidt et al. (1993): Actors, Responsibilities, Tasks,

Activities, Conceptual structures, Informational resources, Material resources, Technical resources, and Infrastructural resources. To facilitate the reading a definition of each of the dimensions will be given in the beginning of each section. These descriptions (definitions) are based on our discussions in Schmidt et al.
(1993
).

5.1 Actors

The actors involved in the work to be articulated are often referenced in mechanisms supporting articulation work. Here we think of references to actual or potential participants in the cooperative arrangement having their cooperative activities articulated (referenced in terms of for example capacities, roles, jobs, individuals, collectives, etc.).

Several different types of actors are using the mechanism, e.g., the testers from the service and marketing department, the spec-team members, the designers, etc. Some of these are not reflected in the mechanism. The form itself has direct pointers to the actual tester and the designer designated to do the corrections. The procedure and conventions for how to handle the forms further prescribes (points at) three other actors that must be notified during the testing, diagnosing, correcting, verification flow, namely the platform master, the spec-team, and the central file manager.

In the concrete social mechanism of interaction described in this paper it seems sensible to distinguish between actors and roles as different dimensions of objects of articulation. In the mechanism testers and responsible designers are named actors (although one could consider this as roles too), whereas platform master and central file manager are roles that the involved actors take turns at.

5.2 Responsibilities

The next type of objects of articulation mechanisms of interaction can point at is responsibility. A responsibility can be defined as a relation between an actor (or a role) and a task, an activity, or a resource.

The form, and thus the mechanism, define a responsibility relation between a task (correction of the problem described in the form) and a software designer (a field in the form). The inclusion of a platform period number on the form in reality means, that a designer has been pointed out as responsible and the deadline for the work has been established. The deadline is not explicitly included, but the reference to a platform period links to another social mechanism of interaction: the spread-sheet based project plan (cf. Section 3.1.4) which explicitly state the deadline. For a thorough discussion of how mechanisms are linked to each other see Schmidt et al.

(1994) in COMIC Deliverable 1.2.

Other responsibility relations are implicitly established (for each form) via the procedures and conventions used: First, by listing the affected modules (applications) in the form, the designers responsible for these modules (reflected in the project plan) are anticipated to check whether the corrections made can affect their modules in any unintended manner. Second, when a designer returns a form indicating that a problem has been dealt with, then, according to the organizational procedure, the platform master become responsible for verifying the correction. A third kind of responsibility embedded in the mechanism is the obligation to forward the forms after having added relevant information. This must be done by all actors according to the organizational procedures and conventions.

5.3 Tasks

A central structure in much articulation work is tasks. A task is defined with respect to its operational intentions (goals to attain, and obligations and commitments to meet), without addressing its actual implementation.

The form itself has only reference to one task. That is the task of correcting the described problem.

However, the procedures and conventions embedded in the mechanism identify a series of tasks and stipulate the sequence of these. The tasks are for example: describe, classify, and prioritize the problem; diagnose the problem; correct the problem; verify the correction; etc. These tasks are not themselves articulation tasks, but the mechanism addresses them in order to articulate them, i.e., we can consider the mechanism as a mechanism relating these tasks to each other by stipulating the sequence.

5.4 Activities

Concrete activities need to be referenced by mechanisms of interaction too. By an activity we think of an unfolding course of purposive action. Only those aspects of a work process that are relevant for doing the work with the currently available resources are included. Other incidents that may occur in the same course of action, but which are of no consequence for getting the work done are eliminated. For a detailed discussion on the distinctions between tasks and activities see for example Andersen et al. (1990), p. 41-44.

The mechanism do not have references (pointers) to any particular activities going on in the testing and correction work. We could argue, that the procedural prescriptions for how to “route” the action steps, trigger a series of activities. None of these are, however, coordinated or in any other way articulated by means of the mechanism.

5.5 Conceptual Structures

To support articulation work mechanisms of interaction often contain references to conceptual structures of different kinds. In this context conceptual structures means relationships between categories or structures used within a specific community as devices for ordering, structuring, or abstracting central aspects of the work. Examples of such conceptual structures are definitions, classification structures, modulations, prototypical structures, causal relations, historical relations, and means-end relations.

One of the major findings in the field study of the software designers at Foss Electric was that both the actual work of software development and testing, and its articulation, to a very large extent was based on abstract structures and conceptualizations of structures in the field of work. The form itself can be regarded as a conceptualization of an identified software problem. It contain several examples of references to conceptual structures used when articulating the software development and testing: First of all several classification structures: A classification of the importance of the bug seen from a tester perspective, a classification of the importance of the bug seen from the software developers perspective, and a classification of the correction to be made related to the working cycle (the platform period). Also there is a direct reference to the modulation used for structuring, and communicating about, the software complex. Furthermore, the entries in the central file (cf. Figure 2-2) reflects the possible states of a reported bug.

5.6 Informational resources

References to informational resources containing information to be used in the work are relevant too. Examples of informational resources are documents, notes, letters, files, reports, drawings, etc.

The mechanism does not contain any references to informational resources apart from the fact, that it can be regarded as a informational resource itself. Each form contains information to be used by the actors. The central file is a source of information intended to be used by all the involved designers and testers.

5.7 Material resources

By material resources we think of material, components, etc. to be used when conducting the work. The mechanism do not have any references to material resources. As a design and construction discipline software design is unique. It do not require any use of material resources to build something.

5.8 Technical resources

Technical resources are resources needed to produce “the product”, e.g., tools, fixtures, machinery, software applications, etc.

The mechanism do not have any direct reference to technical resources apart from a field containing information on which machinery was used when the bug was identified. This is, however, not for articulation purposes, but information to be used when diagnosing the problem. The mechanism works as a medium for carrying information from one actor to another.

5.9 Infrastructural resources

Infrastructural resources are the infrastructural facilities used by the actors when conducting the work. Examples are rooms, buildings, communication facilities, transportation facilities, etc. The mechanism do not have any references to infrastructural resources.

5.10 Other frames of references

Apart from the dimension of objects of articulation work mentioned in the previous nine sections articulation work is always done in relation to a wider context. The context contains demands and constraints posed by the work environment, the state of field of work, and the wider organizational setting. Furthermore, articulation work is always done with reference to time and space (Schmidt et al., 1993). It is thus relevant to address how a social mechanism relates to these "orthogonal dimensions" too.

The state of affairs in the field of work and the nature of the wider organizational setting are not referenced in the mechanism, apart from what have been discussed in the previous sections. Neither are the nature and organization of the cooperative work arrangement (here considered similar to what we called work environment in Schmidt et al. 1993). The bug form mechanism can, however, be described as being part of the structure, that constitutes the work arrangement.

The mechanism do not have any references to space. It contains a reference to which machine has been used when recognizing a bug, but as mentioned earlier this is for information purposes only. There are, however, several references to the dimension of time in the mechanism. For the purpose of documenting the history of the process a form is time stamped several times: When a bug is registered, when it is diagnosed, when it is corrected, and when the corrections are tested. Also the time estimated for correcting a bug, and actually spend are registered.

When analyzing the bug form mechanism as a mechanism stipulating articulation work, the most interesting reference to the dimension of time is the reference to a platform period. This reference is an implicit indication of the importance of the correction. Furthermore it indicates which other tasks the correction task has to be meshed with. These references illustrates the importance of addressing links to other mechanisms when analyzing social mechanisms of interaction.

5.11 Summarizing the objects of articulation and the related functions

A bug form contains references to several different dimensions of objects of articulation. The table below (Figure 5-2) summarize these. As mentioned earlier central aspects of articulation work can be described in terms of functions (or “manipulations” or “operations”) on the structures reflecting the objects of articulation. These functions are listed in the table too.

The first collum contain the dimensions of objects of articulation. Listed in the second collum are the concrete objects referenced in the bug form mechanism. Objects in brackets indicates that these are referenced only via the procedures and conventions in the mechanism. The third collum illustrates the basic operations and functions relevant (for the mechanism described in this paper) in relation to the given object dimension.

Symbolic reference	Symbolic reference in mechanism (the form, the Binder, and the procedures)	Functions in the mechanism
Objects of articulation work		
Actors	Tester Responsible designer (Spec-team) (Central file manager) (Platform master)	Assign
Responsibilities	The form is a responsibility relation between the responsible designer and the correction task identified. (Consider consequences) (Validating corrections)	Allocate, Hand over, Accept, Reject, Negotiate
Tasks	The correction of the bug (the content of the form itself) (Consider consequences) (Validating corrections)	Accept, Reject, Accomplish, Negotiate
Activities		
Conceptual structures	Classification of bugs Modulation of the software Working rhythm (platform periods) Stages for a correction process	Define, Specify, Classify, Relate, Direct attention to, Negotiate,
Technical resources	Test machine	Specify
Informational resources		
Material resources		
Infrastructural resources		
External systems of reference		
Work environment		
Field of work	Classification of bugs Software structure (modules) Files	See conceptual structures above
Organizational setting		
Space		
Time	Platform period Registration time Diagnosing time Correction time Testing time	Specify, Relate to, Negotiate, Refer to

Figure 5-2: A classification and characterization of the symbolic references and functions in the bug form mechanism analyzed in this paper. First collum specifies the dimensions of objects of articulation. Second collum contains lists the objects referenced in the mechanism, and third collum lists relevant operations on the structures. Brackets are used to indicate that the objects are referenced indirectly, i.e., only via the procedures and conventions in the mechanism.

6. Discussion

The aim of this paper is to describe a phenomenon observed in an existing work situation as a social mechanism of interaction. This was done in order to establish a basis for refining and improving the concept of mechanisms of interaction. The present paper had thus a threefold aim: First, to learn some general lessons on what characterizes the articulation of software testing activities. Second, to get a deeper and more coherent understanding of how social mechanisms of interaction supporting articulation work is functioning in a real world work setting. And third, to provide input for an evaluation of the concept of mechanisms of interaction as a tool supporting the analysis and characterization of complex, cooperative work settings. This evaluation must be related to the purpose of the analysis: To discuss and sketch how a computer based support of the articulation activities involved can be implemented.

It was not the intention of this paper to come up with final answers or conclusions to the three research questions mentioned above. Rather, the aim was to provide input for future processes addressing the questions. It seems, however, relevant briefly to start the discussions.

6.1 Characteristics of the articulation of software testing

This section will briefly condense the most interesting aspects of the use of the bug form at Foss Electric and other dominant characteristics of how the articulation of the software testing work in the S4000 project was organized.

The described case indicates, that it can be very difficult for the testers to get an overview of reported errors, their diagnoses, correction status, etc. It was extremely difficult for the actors involved in the S4000 project to determine the state of affairs in the software testing at a glance. It was clearly illustrated in the study, that it was difficult for the testers and designers to communicate about the software complex and its status at a given point in time. The state of affairs was "hidden in abstract representations". This is similar to problems in the process of developing software reported by Parnas and Clements (1986).

For articulation purposes, activities such as allocating resources, planning and scheduling tasks, monitoring the state of affairs in the development and test process, classifying and prioritizing, distributing information, negotiating requirements, and negotiating priorities, etc. are essential. In the S4000 project at Foss Electric these activities were usually done by means of ad hoc meetings and discussions, structured meetings, and use of different forms and lists (for a detailed description cf. Carstensen et al., 1994). The present paper has described one of these forms and its related procedures and conventions in details.

The study furthermore illustrated, that articulation activities in software testing (at least in the concrete case) mainly are based upon conceptualizations of structures in the field of work (e.g., the structure of the software complex) and structures reflecting the current implementation of the cooperative work arrangement (e.g., the involved actors, the working cycles, verification procedures, etc.). An illustration of the most important conceptualizations can be seen in Figure 5-1. In the S4000 project the conceptualizations was, among other things, used to support the distributed bug registration activities, support the planning and monitoring activities, and to simplify the needed bug classification and diagnosing activities.

Furthermore, aggregations of detailed information of the state of affairs (e.g., the total number of "not yet corrected category 2 bugs") was used to support the articulation work, especially in order to simplify the required monitoring activities. Several structures for classification and categorization of bugs, corrections demands, and software modules was used too. Concrete information from the software testing and development work was also used when the activities were articulated, e.g., the software code itself, the documentation of the software, or the content of the bug registrations was used for deciding the estimated correction time for a bug.

If we use a function oriented approach on the articulation activities in the S4000 project, a number of functions (or activities) were predominant during the articulation of the work. The most prominent of these were: classification and categorization of bugs and software, coordination of ongoing activities, monitoring of state of affairs and progress in the processes, allocation of resources, relation of resources to tasks (establishing responsibilities), meshing the resources and tasks into work plans, and negotiations of classifications, allocations, obligations, etc.

The characteristics described above can, of course, be used for a discussion on how to eliminate some of the problems by means of computer support. A discussion of relevant requirements, and a sketch of a computer based mechanisms based on our understanding of the bug form mechanism, can be found in a chapter in COMIC Deliverable 3.3 (Carstensen and Sørensen, 1994b).

6.2 Characteristics of the bug form mechanism

The present paper has discussed the bug form as a social mechanism of interaction, i.e., we have considered the form, etc. as a mechanism used to support handling (reducing) the complexity of the articulation of the distributed activities in a cooperative ensemble doing software testing by stipulating and mediating the articulation work. This definition of the basic function of the mechanism would probably not be recognized by the software designers involved in the S4000 project. This would not reflect their original intentions, or rather their original description of the problem they had recognized when they first developed the ideas of the form. It is, however, quite clear, that the overall purpose of the mechanism was to reduce the complexity of certain aspects of the articulation of the software testing process. This was not done by "eliminating" the complexity, but by standardizing information structures and work flows used. The standardization was achieved, by for example, letting information to be used for the diagnosis be included in the form in a standardized pre-structured manner, and by implementing and using standard procedures and work flows for how to handle the process. The former supports the interaction between the actors by providing a "standardized language". The latter supports the coordination of the involved activities by stipulating the flow of work, and it supports the monitoring of the state of affairs and the progress in the work by establishing a central file including all registered bugs and their current status. It would probably be more or less impossible to handle distributed testing and bug registration involving approximately 20 testers without having a mechanism providing an overall functionality similar to the mechanism described. It would require an enormous number of formal and informal meetings to coordinate all activities and keep all actors up to date.

The purpose of the form and the related procedures and conventions is first of all to ensure that all problems are registered, that responsibilities are clear and visible to all involved designers, and to clearly stipulate how a bug is reported corrected. It was also the intention, that the binder should provide all the involved designers and tester with an overview of the state of affairs in the total software complex. Furthermore the mechanism should support the designers in being aware of activities in modules of which they were not responsible, but to which their modules might have close interaction. The two latter purposes of letting all designers be aware of state of affairs were only partly fulfilled since several of the designers found it to complicated to browse the forms in the binder. As mentioned in the previous section will we not discuss a possible redesign here.

Changes in the mechanism can trigger instantiations of a number of different activities related to the actual work conducted, e.g., start of diagnosing activities, start of correction activities, or start of new testing and verification activities.

In terms of objects of articulation the mechanism mediates and stipulates the articulation of the software testing via conceptualizations (or rather pointers to structures) of tasks, actors (roles), software modules, responsibilities, and deadlines.

The aim of this paper was to provide input for improving, changing, and refining the concept of mechanism of interactions. The implicit and explicit results of this and other field studies (empirical evaluations) can be found in part 1 of this book, and in chapter 3 of COMIC Deliverable 3.3 (Simone et al., 1994). Some preliminary reflections will be given here.

First of all, the definition of what is a mechanism of interaction seems to be too strict. In Schmidt et al. (1993) we defined a mechanism of interaction as an artifact that (to some extent) actively stipulated and mediated the articulation of distributed activities. In real life work situations most mechanisms supporting articulation work are not active artifacts. Rather, they are forms, schemes, or boards (cf. e.g., Borstrøm et al., 1994) containing information relevant for the articulation of the work coupled with a set of related conventions and procedures. The artifacts themselves are thus passive information containers, the stipulation is specified by the conventions and procedures, and it is the actors who are the active in making things happen (usually by following the procedures). Hence, a broader definition of mechanisms of interaction is needed, or perhaps two definitions: A open-minded one to be used when identifying candidates for mechanisms of interaction in existing work settings, and a more restricted one to be used when specifying the characteristics of an active (computer based) mechanism.

With respect to the dimensions of objects of articulation in the concept of mechanisms of interaction a number of things can be refined. The reported study has exemplified, that the actor dimension needs to be separated in two dimensions: One of “actors” referring to the actual actors involved in the work, and one of “roles” referring to the role an actor has in relation to a given task or activity. In the S4000 project all the software designers had several different roles which was important to explicitly address when articulating the activities.

Furthermore we need to separate along the dimension of time. Some tasks are planned along the dimension of resources available in the period where the task must be accomplished. At any given point in time some activities using named resources are ongoing. These require coordination. For monitoring purposes historical information must be available too, i.e., be able to back track what has happened with respect to the time dimension. This might call for a three layered set of dimensions of objects of articulation: (1) planned or potential, (2) present or ongoing, and (3) past.

A third comment to the existing dimensions of objects of articulation concerns the dimension of responsibilities. In opposition to the rest of the dimensions, responsibilities are always relations between two or more other dimensions, typically between task and actor. It would be relevant to reconsider the dimensions and support different types of relations between the dimensions. The existing concept could be improved by focusing on, how the concrete objects of articulation are related to each other.

A thorough discussion of the dimensions of objects of articulation is given in Chapter 1 of COMIC Deliverable 3.3. The changes in the structure for how to model the objects of articulation are illustrated in Figure 6-1 below. This figure provides the same overview of the objects of articulation referenced in the bug form mechanism as given in Figure 5-2. Figure 6-1 is, however, based, on the refined structure of the object of articulation. The changes will not be discussed in this paper.

<table>
<tr><th colspan="2">Nominal</th><th colspan="2">Actual</th></tr>
<tr><th>Objects of articulation work</th><th>Operations with respect to objects of articulation work</th><th>Objects of articulation work</th><th>Operations with respect to objects of articulation work</th></tr>
<tr><td colspan="4">Articulation work with respect to the cooperative work arrangement</td></tr>
<tr><td>Role
- Tester
- Responsible designer
- Spec-team member
- Central file manager
- Platform master</td><td>assign to [Committed actor];
responsible for [Task]</td><td>Committed actor</td><td>assume, accept, reject [Role];
initiate [Activity];</td></tr>
<tr><td>Task
- Correction task</td><td>relate;
allocate;
accept;
reject;
accomplish;
approve;
disapprove;</td><td>Activity</td><td>initiate [Committed actor];
done by [Actor-in-action];
realize [Task];
make publicly;</td></tr>
<tr><td>Human resource
- James
- Jones
..</td><td>locate, allocate, reserve;</td><td>Actor-in-action</td><td>initiates [Activity];
does [Activity];</td></tr>
<tr><td colspan="4">Articulation work with respect to the field of work</td></tr>
<tr><td>Conceptual structure (conceptualization of field of work)
- Bug classifications
- Software modulation
- Platform periods</td><td>define;
relate;</td><td>State of field of work</td><td>classify, instantiate;
direct attention to,
make sense of;
act on;</td></tr>
<tr><td>Informational resources</td><td></td><td></td><td></td></tr>
<tr><td>Material resources</td><td></td><td></td><td></td></tr>
<tr><td>Technical resources
- Test machine</td><td>categorize;</td><td>Technical resources-in-use</td><td>categorize;</td></tr>
<tr><td>Infrastructural resources</td><td></td><td></td><td></td></tr>
</table>

Figure 6-1: The objects of articulation as previously described (in Figure 5-2) illustrated by means of the refined concept of mechanisms of interaction.

6.3 The concept of mechanisms of interaction as a tool for work analysis

During the analysis and description of the findings from the field study the concept of mechanism of interactions has been used to identify and structure relevant aspects of the findings. Hence, it is obvious to reflect upon of the usefulness of the concept as a tool supporting work analysis, i.e., discuss the usefulness with respect to supporting a requirement specification process and a process of designing a computer based mechanism.

Some of the comments to the concept given in the previous sections are equally relevant here. For example, the aspect of explicitly addressing how the identified objects of articulation are related to each other, is very important for an analysis too.

The most important comments to the concept of mechanisms of interaction so far are:

- The concept is based on analytical distinctions between work and articulation work, and between field of work and cooperative work arrangement. These are very fruitful because they forces the analyst to explicitly address aspects that usually are addressed as intertwined with other things. Although we, when designing computer based systems, need analysis methods that grasps the richness of the work as a whole, it seems relevant in some situations to delimits aspects not addressing the articulation of work. We need, however, to address the fact that work and its articulation is closely related and intertwined too.
- In many existing complex work settings certain aspects of cooperation might simply have been avoided because of the complexity of the articulation of the work. As analysts we need support for identifying these situations, since we have to reflect upon whether use of more advanced technology would enable the cooperation, that previously was considered as impossible or too problematic. By providing some kind of support for identifying these situations the usefulness of the concept could be improved.
- One of the conclusions of the described study is, that a functional approach to conventions, procedures, artifacts, etc. used to support the articulation of the work is essential. In order to identify candidates for computer based mechanisms of interaction we need a way to identify, not only which procedures are used, but also to identify the purpose or the goal of a procedure, i.e., what does a procedure strive to ensure or handle? It will otherwise be difficult to understand the procedures in terms of what articulation work function it supports. Thus, it seems essential to approach existing social mechanisms in a functional manner. The term “existing” must be understood in the broadest possible manner, i.e., also including processes, that are handled by means of conventions or vague procedures.
- An analysis approach cannot be based on observation based methods only. When observing the software testing process in the S4000 project very little

happened in long periods of time. Thus, we need methods based on interviews or other means for getting in direct interaction with the actors.

We are, as analysts, basically interested in computer based support of articulation work activities. It is thus essential to address the possible conceptualizations of the structures used when articulating work, and possible operations and actions required when addressing the structures. Hence, the approach must contain some kind of conceptual framework for identifying and describing these structures. The existing concept of mechanisms of interaction contains structures that supports some of these aspects in a very promising way.

A few summarizing remarks on how to improve the concept of mechanism of interaction as a tool supporting work analysis: The structures in the concepts need some further improvement and refinement (cf. Section 6.2). A functional approach to mechanisms of interaction could be included. Techniques and methods that supports the identification of candidates for computer based mechanisms of interaction would improve the usefulness. When building concrete computer based support system we will have to support both the cooperative work aspects and articulation work aspects. It will thus improve the concept if it reflects an understanding of how the articulation work and the actual work is intertwined.

It is important to notice, that the concept of mechanisms of interaction were not originally established with the purpose of supporting analysis of cooperative work. It contains, however, a set of promising ideas that makes it obvious to work towards this direction too.

Acknowledgments

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The augmented bill of materials

Carsten Sørensen

Risø National Laboratory

Traditionally, the Bill of Materials is used to manage the production of components and units. The Bill of Materials specifies the number and types components which goes into making sub-assemblies, and the type and number of sub-assemblies that goes into making units or finished products. Hence, the Bill of Materials is basically a tree-structure making it easier to cope with the complexity of a multitude of interconnected parts. Material Resource Planning (MRP) production scheduling systems are based on Bill of Materials. At Foss Electric they had over the years used an ordinary Bill of Materials in order to manage the production of prototypes and test series of instruments. Because Foss Electric has implemented a concurrent engineering mode of operation, development projects test the fundamental ideas, the detailed designs, and the production and assembly system in a series of prototypes. There is, hence, a substantial element of production planning and control even in the development phase. As the instruments got more and more complex, this work became more and more complex. In order to cope with the complexity, the participants engaged in weekly meetings. In these meetings the participants reviewed Bills of Materials and blue-prints in order to obtain a common understanding of the state-of-affairs and in order to make decisions regarding changes to the various specifications. In order to reduce the need for this weekly meeting, the Augmented Bill of Materials was designed. Apart from containing all the information on the regular Bill of Materials, it also includes a number of symbolic references to objects of articulation work and to external systems of reference. A written organizational procedure stipulates the process of reviewing, annotating, updating, and sending the Augmented Bill of Materials and blue-prints.

1. Purpose of the Augmented Bill of Materials

At Foss Electric, the development from idea to final product involves a number of intermediate products: (1) A product concept defining the overall architecture and interaction between the involved technologies; (2) a few functional models (mock ups); (3) five to ten prototypes of the instrument used for verifying detailed ideas and designs; and (4) a test series of five to ten instruments in order to test manufacturability of the product. Development projects at Foss Electric test designs by producing these different types of intermediate products. This is, of course, only feasible because of the type of products the company manufactures, and because they do not use any specialized production tools. If they were mass producing components using a substantial amount of tools such as specialized fixtures, stamping tools, casting tools etc., this prototyping approach might not be feasible. Also, if they were in the business of one-of-a-kind production, this approach would be problematic.

Because Foss Electric produce prototypes as an integrated part of the development process, they need to plan and control the production of parts. Prior to the

S4000 project, Foss Electric had used a Bill of Materials as a means of handling the complexity of this production (for a description of Foss Electric and the S4000 Project, see Appendix A). A Bill of Materials (BOM) is a hierarchical structure which describes the breakdown of components into parts. For each item gets an identification code and it is specified how many of each item is used to make up a component or unit. Figure 1 shows an example of such a BOM taken from Gunn (1987). The BOM is typically used for production scheduling and control in MRP systems (Gunn, 1987; Schmidt, 1993).

Item #	Description	Quantity
47342	Mounting Kit, Basic	1
76504	Bracket, cast	1
64333	Bolt, 5"/16x24x1"	2
30751	Nut, 5"/16x24	2
22479	Washer, flat, 5"/16	2
22842	Washer, lock, 5"/16	2
16935	Clamper assembly	1
88327	U bolt	1
30750	Nut, self-lock, 5"/16x24	2

Figure 1: Example of a typical Bill of Materials (BOM) used in production control.

The S4000 project was characterized by a relatively large number of both mechanical components, as well as project participants. These circumstances led to the invention of an Augmented Bill of Materials (ABOM) (see Figure 2 and 3).

Prior projects, using a standard BOM, used weekly meetings as a means of articulating the state of affairs pertaining to the production of components. The paper-based ABOM, together with an organizational procedure, reduces the complexity of handing over CAD models for components from engineering design to process planning and production. It also serves as input for scheduling in production. The organizational procedure stipulates who is responsible for which tasks when producing components for experiments, functional models, and prototypes.

2. The Augmented Bill of Materials

The artifact itself is basically a sheet of A4 paper (see Figure 2). The form is made in Word Perfect. It consists of a header, 16 columns and 19 rows. A subset of the ABOM is the data in the ordinary Bill of Materials.

STYKLISTE forsøg/funktionsmodel/prototype

APP. ______ TYPE NR. ______ ANTAL APP. ______ SIDE ___ AF ___ SIDER

ENHED ______ KONSTRUKTØR ______ TEGNER ______ DATO ______

DEL NR + UDGAVE NR	BENÆVNELSE	MODEL FIL NAVN	STK/ APP	STK MO-DEL-V.	STK UDE-FREM ST.	STK MASK. VÆRK-STED	OVFB	NY RÅ-VARE	MASK. NR.	CAM PROG.	MÅLE PROG.	VF	LEV. UGE	ALT. LEV. UGE	FORV. PROD. TID
TEGNER	TEGNER	TEGNER	TEGN.	TEGN.	PLMV	PTA	P.I.	TEGN.	VF	VF	PTA	VF	PLMV	PLMV	PLMV

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KONTROLLERET AF PTA ______

Figure 2: The Augmented Bill of Materials as the artifact is used at Foss Electric.

Figure 3 shows a translated version of the ABOM with the header as in the original and with the rows converted to columns for presentation purposes. In the following all references to rows or columns are relative to the re-drawn and translated version in Figure 3. Please note that all in *italics* in Figure 3 are annotated explanations of content and type of data field in the form. In the following numbers marked as *(1)* refers to the numbers added to the fields in the ABOM in Figure 3.

Augmented bill of materials: Experiment/functional model/prototype				
Instrument: *Name (1)*	Type ID: *ID number (4)*		Page of pages *(7)*	
Unit: *Unit name (2)*	Batch size *Integer (5)*		Date: *(8)*	
Designer: *Name (3)*	Draught person: *Name (6)*			
Categories	*1. component*	*2. comp.*	*19. comp.*	*Responsible*
Component ID	*ID + version*	*(9)*		Draught person *(25)*
Description	*Text*	*(10)*		Draught person *(26)*
Model name	*Model database ID*	*(11)*		Draught person (27)
# Pr. instrument	*Integer*	*(12)*		Draught person *(28)*
Model shop	*Check*	*(13)*		Draught person *(29)*
Subcontractor	*Check*	*(14)*		Production planner *(30)*
Production	*Check*	*(15)*		Process planner *(31)*
Surface processing	*Check*	*(16)*		Project purchaser *(32)*
New input materials	*Check*	*(17)*		Draught person *(33)*
Machine ID	*ID number*	*(18)*		Foreman *(34)*
CAM program	*Type of CAM prog.*	*(19)*		Foreman *(35)*
Measure program	*Check*	*(20)*		Process planner *(36)*
Foreman	*Initials of foreman*	*(21)*		Foreman *(37)*
Delivery week	*Week number*	*(22)*		Production planner *(38)*
Alt. delivery week	*Week number*	*(23)*		Production planner *(39)*
Production time	*Estimated time*	*(24)*		Production planner *(40)*
Controlled by process planner: *Signature (41)*				

Figure 3: The Augmented Bill of Materials (ABOM). Each ABOM form holds information of up to 19 components for the same unit in the same instrument. The original is inverted, i.e., the rows in the figure are columns in the original ABOM. The original has 19 rows, corresponding to 19 different components. These are illustrated in three columns. This inversion is made in order to depict the whole ABOM and not only part of it. All italics are our additions. For each category of field in the form, the type is indicated. The bracketed numbers are used for referring to the individual fields.

The header contains information about the name of the instrument which is being developed *(1)*. The names of the designer *(3)* and the *(6)* draught person are listed. The header also contains information about the unit which the ABOM is describing components for; the name of the unit *(2),* type ID *(4)* and batch size *(5)*. Lastly there are fields for data on page numbers *(7)* and the date the ABOM is instantiated *(8)*. The major part of the ABOM contains information pertaining to the production of components.

Data on the identity of components are described in fields *(9–12)*; component ID *(9)*, a short textual description of the component *(10)* which is rarely used because it is considered sufficient to use the name of the component in the data management system *(11)*, and the batch size of the particular component *(12)*.

As it can be seen from comparing the ordinary BOM (Figure 1) with the ABOM (Figure 3), the fields *(4)* and *(9)* corresponds to the item ID's — first column in the BOM. The fields *(2)* and *(11)* corresponds to the names of units and components in the BOM — second column. Fields number *(5)* and *(12)* corresponds to the quantity in the BOM — third column.

The ABOM also contains information on where the components are going to be produced — the division of labor between the model shop *(13)*, a subcontractor

(14), or the production department at Foss Electric *(15)*. If the component is to be surface processed field *(16)* is ticked off. Components for experiments and functional models are generally not surface processed because of the added costs of this process. Prototype and test-series instruments are, however, sold and hence components are surface processed. If producing the component implies using a new input material, field *(17)* is ticked off.

The information in the fields *(18–24)* has to do with arranging and scheduling the production of parts. The number of the machine on which the part is going to be produced is written in field *(18)*. The type of CAM program required is written in field *(19)*. There are three basic types of CAM programs at Foss Electric corresponding to the three basic production processed applied; bending, milling and turning. In case of production of complex parts, a measurement program might be needed in order for quality assurance to be performed properly. This is indicated by a cross in field *(20)*. The initials of the foreman responsible for manufacturing the part is added in field *(21)*. The delivery week is written in field *(22)*. If this deadline for some reasons can not be met, an alternative delivery week is indicated in field *(23)*. The estimated production time is written in field *(24)*.

The roles responsible for the content of the fields *(9–24)* are stipulated in the form in fields *(25–40)*. Lastly, the responsible process planner signs the ABOM form in field *(41)*.

3. The Procedure of Using the ABOM

The ABOM is filled in and used in a distributed manner. In order to coordinate work in relation to blue-prints and ABOM's, an organizational procedure has been written. The procedure was written in connection with designing the ABOM in the S4000 project. The organizational procedure ensures that blue-prints and ABOM's are reviewed, corrected and distributed to the various persons and departments. Furthermore, it ensures that certain actions are taken in relation to blue-prints and ABOM's, e.g. defining new entries in the MRP II system COPICS. Figure 4 shows a condensed overview of the routing of the ABOM and blue-prints as stipulated in the organizational procedure. The diagram focuses on the roles involved in sending and receiving ABOM's and blue-prints. The diagram is to be read from the top and downwards. A translation of the organizational procedure is shown in Figures 5–8.

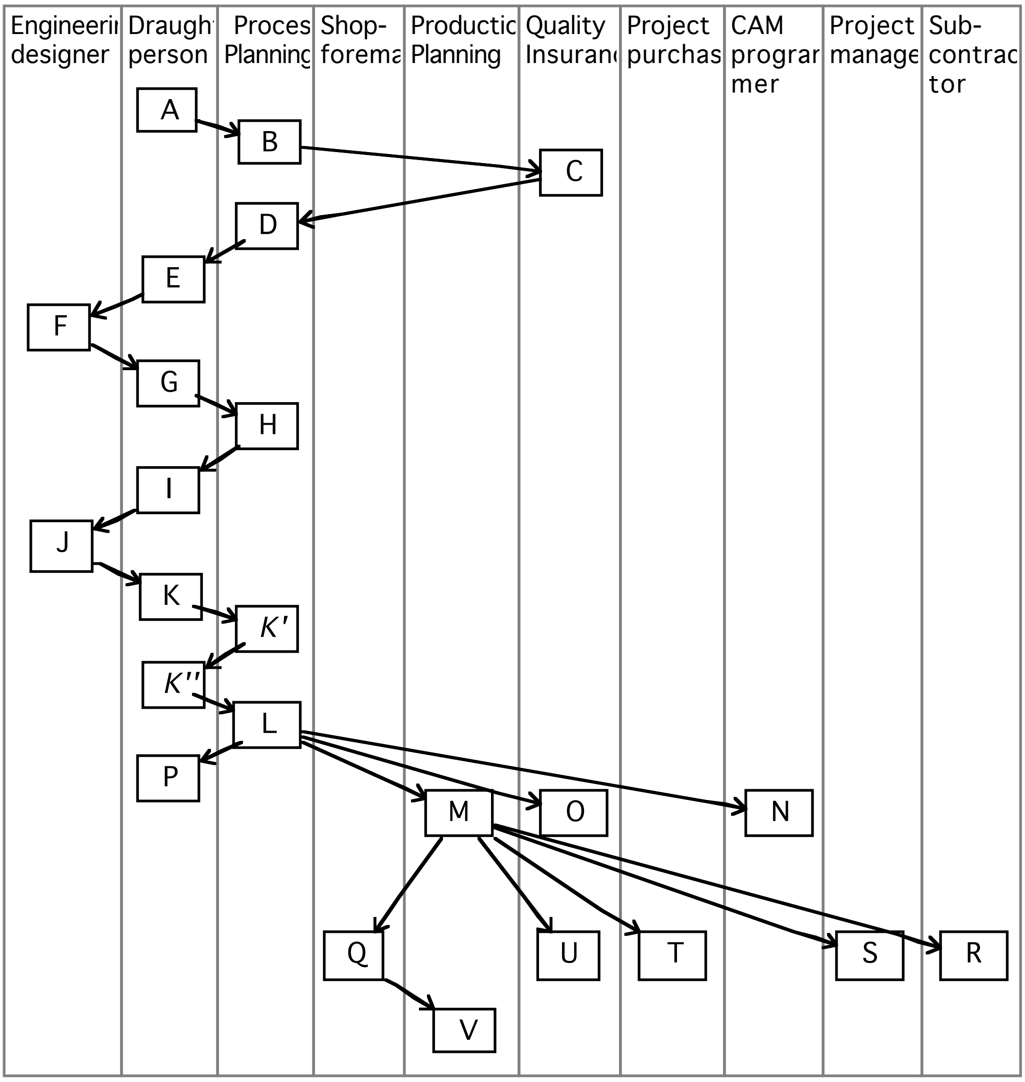

Figure 4: The workflow of the combined set of ABOM and blue-print as derived from the written organizational procedure shown in Figure 5 and 6. The workflow is read top-down. K' and K'' indicates that the procedure is ambiguous and hence is subject to interpretation.

In general, the system consists of an organizational procedure stipulating the roles, responsibilities and tasks involved in both distributed circulation, review and annotation of blue-prints, as well as in distributed annotation of decisions in relation to ABOMs. In the following, the major phases in the use of the ABOM and blue-prints are outlined, based on the organizational procedure. The capital letters refer to paragraphs in the procedure.

A→B: The engineering designer and draught-person fills in the information in the header (fields *(1–8)*). When the draught-person has finished polishing the CAD model for a particular component or a unit of several components, the model is sent to process planning via a server. He or she then fills in fields *(9–13, 17)* containing information for each component, i.e., component ID, version number, textual description, database ID, batch size, whether the component is to be produced by the model shop, and whether new input materials are to be used. Two copies of blue prints and the master ABOM are handed over, or sent by internal mail, to the responsible process planner.

B→C: The process planner sends one of the blue print copies to Quality Insurance.

PART 1: PROCEDURE FOR MANUFACTURING PARTS FOR EXPERIMENTS, FUNCTIONAL MODELS AND PROTOTYPES

	Responsible	**Task**
A→B	Draught-person	• 2 copies of the original blue-prints are sent to Process Planning and Quality Assurance.
A	Draught-person	• Preliminary ABOM instantiated (part ID, name, file name, # pr. instrument, new input material). Each time a new component is added for a unit, define a new ABOM.
A→B	Draught-person	• Copies of blue-prints and master-ABOM is to be sent to Process Planning.
B→C	Process Planning	• 1 copy of blue-prints is to be sent to Quality Assurance.
C→D	Quality Assurance	• Review blue-prints and add changes. • Hand over blue-prints to Process Planning
D→E	Process Planning	• Review blue-prints and add changes. • Changes from Process Planning and Quality Assurance are annotated on one joint blue-print. • The ABOM is filled in (measurement program and controlled by Process Planning) • Message to draught person about transfer to GNC. • Blue-prints are handed over to draught-person. • Simple blue-prints are normally handed over within 1 day. • Complex blue-prints and the ABOM is are normally handed over within 3 days.
E→F→ G→H→ I	Eng. designer Draught-person Process Planning	• The changes are reviewed. • Delivery-time is determined and added to ABOM.
I→J→K	Draught-person	• In cooperation with engineering designer, the number of components in process at the model shop is annotated the ABOM.
K	Draught-person	• 2-D blue-prints and 3-D models are fixed
K	Draught-person	• Parts-numbers are published in COPICS. Component bill of materials are published in COPICS. COPICS-names can be changed at a later stage, if components are renamed when they are put into the data management system.
K → *K'* → *K''* K''→L L→P	Draught-person *Process Planning* *(interpretation)* *Draught-person*	• 2 copies of blue-prints, and 1 extra copy for components which require measurement programs, + master ABOM is handed over to Process Planning (normally within 1 week after the review). • The total number of components to be produced in production is added in the field "production" on the master ABOM. • All copies of blue-prints are stamped "PROTOTYPE" • All copies of blue-prints + 2 set of copies of the ABOM is handed over to Process Planning • Master ABOM is archived by draught-person

Figure 5: Part 1 of the written organizational procedure used when manufacturing parts for experiments, functional models and prototypes at Foss Electric. The letter in the leftmost column refer to the workflow graph in Figure 5.

C→D: In Quality Insurance, the blue prints are reviewed and changes are added. The changed blue prints are handed over to Process Planning.

D→E: The process planner also reviews the blue prints and add changes. Changes made on the two copies of blue prints are collected on one blue print by the process planner. The process planner fills in the field “Measure program” *(20)* and signs the form *(41)* in the ABOM. Corrected blue prints and ABOM are handed over to the draught person. Simple blue prints are handed over within one day. Complex blue prints are handed over together with the ABOM within three days.

E→F→G→H: The draught person, the engineering designer and the process planner review the changes and determine delivery dates for the components *(22)*.

PART 2: PROCEDURE FOR MANUFACTURING PARTS FOR EXPERIMENTS, FUNCTIONAL MODELS AND PROTOTYPES

	Responsible	Task
L→ {M,N,O }	Process Planning	• Work-schedules are filled in. • Work-schedules + 1 copy of blue-prints and ABOM’s are handed over to Production Planning. • 1 copy of blue-prints are handed over to programmer. • The extra copy for making the measurement program is handed over to Quality Assurance.
M→ {Q,R, S,T,U}	Production Planning	• Allocation code V2 is instantiated on BMIT in COPICS. • Route + order is instantiated. • Production planner receive work-forms from IT • Form marked “PROTOTYPE”, the blue-print and a copy of the ABOM is handed over to shop-foreman. • Copies of ABOM are handed over to project manager + Process Planning + Project Purchasing + Quality Assurance + sub-contractor. • Response-time maximum 1 week.
Figure 9	Process Planning	• Status meetings (see appendix)
M	Production	• Components are normally delivered within 3 weeks, inclusive production by sub-contractor, input material purchasing and material control, but exclusive surface processing.
Q	Shop foreman	• Machine number, CAM program and shop foreman are annotated on ABOM.
V	Production Planning	• When work-forms have been received, the allocation code on BMIT is changed from V2 to V3.
T	Project purchaser	• Input materials inventory sends a raw-materials request form to Project Purchasing, which in turn adds on account number and signature, and sends the form back to the input materials inventory.
	Process Planning	• Upon changes in delivery time the project manager /engineering designer must be notified, minimum once a week.
	Project purchaser	• Pick up components each day • When components have been delivered, the order is closed.

Figure 6: Part 2 of the written organizational procedure used when manufacturing parts for experiments, functional models and prototypes at Foss Electric. Letters in the leftmost column refer to the workflow graph in Figure 5.

I→J→K: The engineering designer and the draught person determine the number of components being made in the model shop *(13)*. The draught person then: fixes the CAD models and blue prints according to the changes suggested and enters parts numbers in the MRP II system COPICS. In “K” there are a slight ambiguity in the organizational procedure. The procedure stipulates that the draught person is responsible for filling in the number of parts to be produced in Production *(15)*. We have interpreted the procedure so that “K” should have been divided into three steps, where the draught person is responsible for sending two copies of the blue prints plus an extra copy of prints for parts which require measurement programs, and the master ABOM to Process planning. The process planner is then responsible for filling in the number of parts to be produced in Production *(15)*. The process planner sends the master ABOM back to the draught person. The draught person then stamps blue prints and ABOM as "PROTOTYPE" in order to be able to distinguish between them and finished production prints, and send copies of blue prints and two copies of the ABOM to the process planner. the draught person then files the master ABOM.

L→{M,N,O}: The process planner fills in work schedules for production of each of the parts to be produced in Production. The work schedules and one of the ABOM copies are then sent to Production Planning. One copy of the blue prints is handed over to the CAM programmer, and the extra copy for programming the measurement program is handed over to Quality Assurance.

M→{Q,R,S,T,U},: The production planner adds information in COPICS and receives work-forms from the IT department. The work-forms are stamped as "PROTOTYPE". The production planner then hand over the work-forms, the blue-prints and a copy of the ABOM to the shop-foreman.

Q→V: The shop-foreman fills in the machine number *(18)*, type of CAM program *(19)*, and his or her own initials *(21)* on the ABOM.

CHANGES

Responsible	Task
Draught-person	• 2 copies of blue-prints with changes annotated in red are handed over to Project Purchasing. • Changes on ABOM are on 1 copy to be marked in red and the ABOM is handed over to Project Purchasing. Remember to correct date on ABOM.
Draught-person	• The 2 copies of blue-prints are stamped "PROTOTYPE" and handed over to Process Planning. • The 2 copies of the ABOM are handed over to Process Planning. • If a measurement program is produced, then notify Process Planning and Quality Assurance.
Production Planning	• Changes and deletion of master in RTRT in COPICS are only to be made by Production Planning.

Figure 7: Procedure for propagating changes made to blue-prints or ABOM.

Figure 7 shows a translated version of the procedure stipulating what the draught-person and the process planner has to do in case of changes made to blue-prints and/or the ABOM. The draught-person sends two copies of blue-prints and/or ABOM with annotated changes in red to Project Purchasing. Similarly, the draught-person sends two copies of blue-prints and/or ABOM to process Planning. If a measurement program is involved, Process Planning and Quality Assurance are notified explicitly. The procedure then stipulates that changes in COPICS only are to be made by the process planner.

BEFORE TEST SERIES

Responsible	Task
Process Planning	• Route is changes. • Schedules and schedule-types are corrected and surface processing is added
Production Planning	• Report on all parts which are to be surface processed is handed over to Process Planning.

Figure 8: Procedure for making changes.

Because the test series of instruments are to be sold, the transition from producing functional models and prototypes to producing test series is marked by a procedure (see figure 8) stipulating which measures Process and Production Planning must take. This has primarily to do with surface processing of parts, e.g. painting.

The diagram in Figure 9 shows how the procedure of producing parts for prototypes and test-series is depicted at Foss Electric. The diagram provides an over view of the process, and emphasizes on stipulating meetings between Process Planning, shop-foremen, sub-contractors, Production Planning, Quality Assurance, and Project Purchasing in order to coordinate the process. In other words, the ABOM system supports some of the basic articulation work between the development group and the other involved manufacturing functions. Still, in order to manage and perform the production process, Process Planning, Production Planning, Shop-foreman, Production, Quality Assurance, Project Purchasing, and sub-contractors need to engage in regular meetings with the purpose of negotiating and monitoring state-of-affairs.

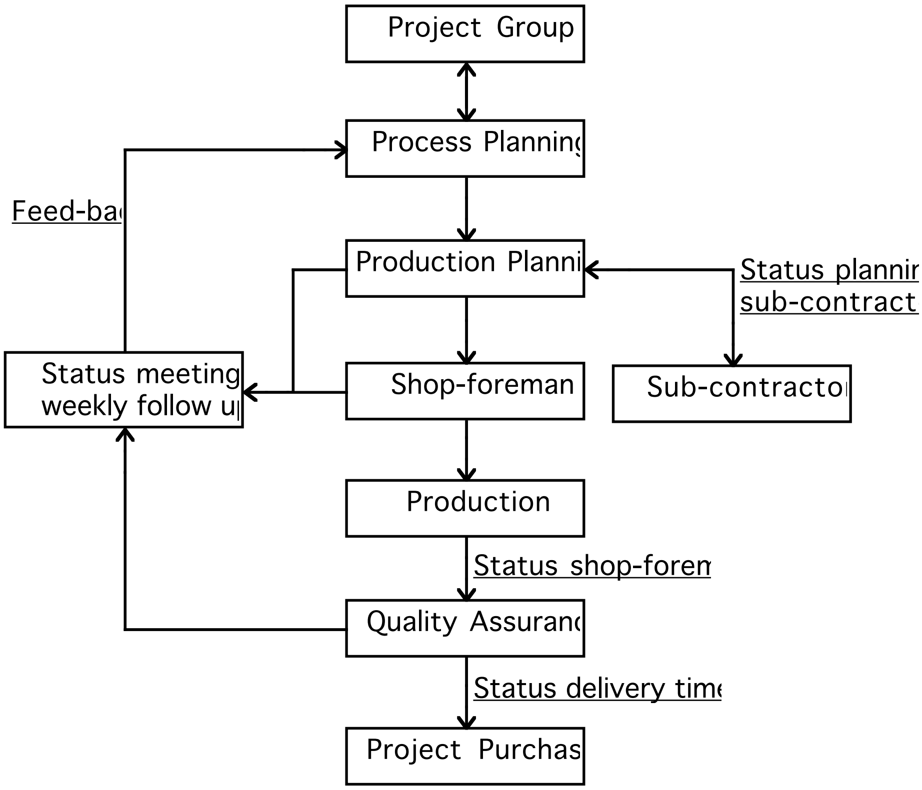

Figure 9: Reproduction of a diagram from the organizational procedure stipulating the generic process of producing parts for prototypes and test-series.

The system consisting of the organizational procedure for producing parts, the ABOM and blue-prints is from time to time discussed. This is mainly triggered by one or more actors being dissatisfied with how the system works. We have extensive data on two such situations. The first led to changes in the system and the other is still under consideration. Both examples has to do with the coordination between Production and Project Purchasing in relation to delivery time for parts.

The first example of problems with the use of the organizational procedure and the ABOM is reflected in minutes from a meeting. Project Purchasing had raised the problem of allocating responsibility for determining which parts should be surface processed. Some parts are surface processed in Production, some are surface processed in the Model Shop, some are surface processed by sub-contractors instantiated by Production, and lastly some parts are surface processed by sub-contractors instantiated by Project Purchasing. Project Purchasing is interested in controlling all surface processing done by sub-contractors in order to cut costs by processing larger batches. Production, on the other hand, is interested in maintaining maximum flexibility. The main reason for Project Purchasing having a problem with the way the system works is that the delivery time indicated in the ABOM sometimes includes surface processing and sometimes not. If Production is doing the surface processing, this process is included in the delivery week stipulated. If surface processing is going to be made by a sub-contractor, it is not.

The second example also has to do with potential ambiguities in stipulating delivery time for parts *(22–23)*. If a part as defined in one of the lines in the ABOM actually is a sub-assembly for a more aggregated part in the unit specified in the header *(2)*, the project purchaser can not always use the delivery week as an indicator for when to look for the part in the inventory. The delivery week specified for this particular type of parts only indicates when the part is produced in Production, not when the part is delivered to inventory as part of an aggregated component. This problem could be solved by adding an extra field in the ABOM named “internal delivery week”. The week number in this field would then indicate when the part is produced and waiting to be assembled. The “Delivery week” field *(22)* would then in all cases make it possible to indicate when parts can be found in the inventory. The discussions led to a modification of the organizational procedure and of the ABOM. Unfortunately this was instantiated as we ended the field study, and we do therefore not have the updated versions.

The updates and triggers of the ABOM basically falls into three categories:

1: One or more fields are filled in by one of the participants: this leads to the ABOM being handed over to the next in line.

2: One or more copies of the ABOM is being distributed to one or more persons

3: A deadline for sending the ABOM is being exceeded. The procedure for handling the ABOM stipulates several deadlines.

In order to characterize the updates and triggers, the changes in states and the transitions of the ABOM from empty to filled form are shown in the diagram in Figure 10.

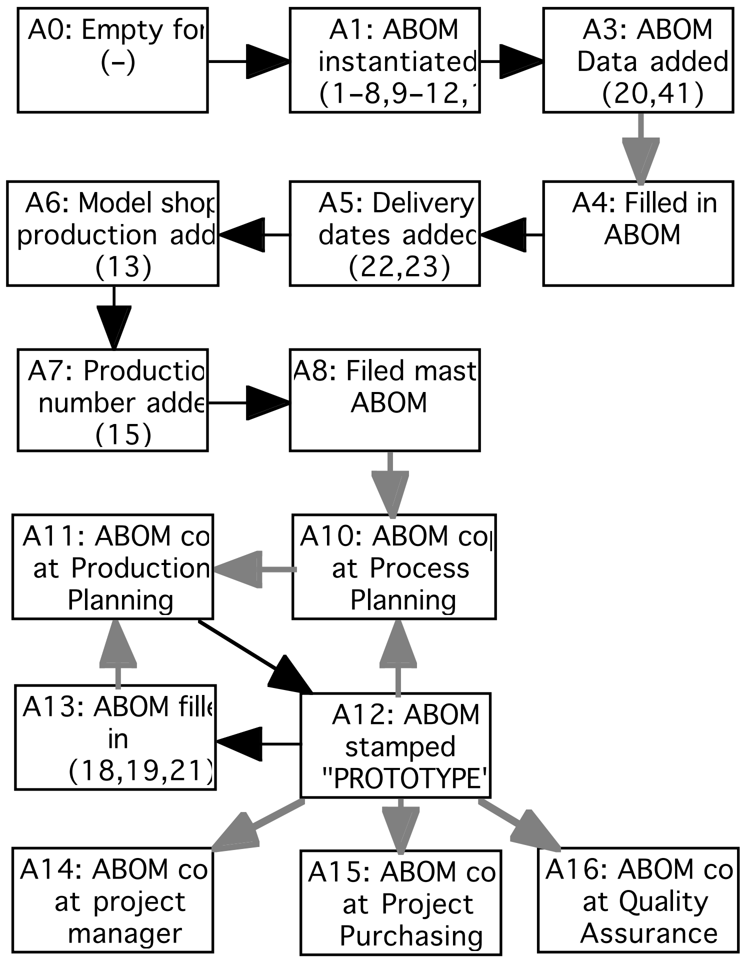

Figure 10: The states and transitions of the Augmented Bill of Materials.

4. Reducing the Complexity of Articulating Changes

The ABOM is rather comprehensive in terms of symbolic references to objects of articulation work and external systems of reference. The ABOM supports distributed dispersion of tasks and responsibilities among actors and functions. The technical resources needed in connection with relevant tasks are also contained in the ABOM, i.e., the type of NC program and the designated machine. If new input materials for the component are to be used, there is a check-mark in a box, hence, there is a reference to material resources. The ABOM also contains references to field of work through the header, e.g., instrument and unit name, and batch size. References to time are made through the deadlines and the estimated times of delivery. As stated earlier, the ABOM represent an extension of a conventional bill of materials (BOM). When the BOM was used they also had the need for weekly meetings in order to negotiate, coordinate, and manage the distribution of tasks and responsibilities. The ABOM made these meetings redundant. It is reducing the complexity of articulation work among actors with different responsibilities regarding design, process planning, and production of components for prototypes and test series by, in a standardized way, structuring the route and relevant options a certain component or unit is going through.

Figure 11 characterizes the objects of articulation work in the ABOM system.

Nominal		**Actual**	
Objects of articulation work	**Operations with respect to objects of articulation work**	**Objects of articulation work**	**Operations with respect to objects of articulation work**
Articulation work with respect to the cooperative work arrangement			
Role: *- Draught person* *- Engineering designer* *- Process planner* *- Production planner* *- Sub-contractor* *- (Quality Assurance) in procedure* *- (CAM programmer) in procedure* *- (Project manager) in procedure*	assign to [Committed actor]; responsible for [Task, Resource]	Committed actor: *- Draught person* *- Engineering designer* *- Process planner* *- Foreman*	assume , accept, reject [Role]; initiate [Activity];
Task: *- Model shop order* *- Sub-contractor order* *- Production order*	point out, express; divide, relate; allocate, assume, volunteer; accept, reject; order, countermand; accomplish, assess; approve, disapprove;	Activity	
Human resource: *- Shop foreman*	locate, allocate, reserve;	Actor-in-action	
Articulation work with respect to the field of work			
Conceptual structure (conceptualization of field of work)	define, relate, exemplify;	State of field of work: *- Classification of types of CAM programs: Milling, turning, stamping* *- Instrument name* *- Type ID* *- Unit name* *- Batch size* *- Component ID* *- Component description* *- # pr. instrument*	classify, instantiate; direct attention to, make sense of; act on;
Informational resources *- Component ID* *- Model name*	locate, access, block; read, interpret, relate;	Informational resources-in-use:	
Material resources: *- New input materials*	categorize; locate, procure, allocate, reserve;	Material resources-in-use	
Technical resources: *- Machine ID* *- CAM program* *- Measurement program*	categorize; locate, procure, reserve;	Technical resources-in-use	
Infrastructural resources		Infrastructural resources-in-use	

Figure 11: Classification and characterization of the symbolic references and functions in the ABOM. Text in *italics* is the characterization of the ABOM.

Acknowledgments

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The CEDAC board

Carsten Sørensen

Risø National Laboratory

Developing an instrument at Foss Electric is a very complex process. In most instruments mechanical, electronic, software, and chemical components interacts. Before an instrument is ready to be produced and sold, an abundance of detailed decisions has to be made. Each decision made by a participant can potentially affect decisions to be made by others. It is, therefore, important to ensure both participants' awareness of state-of-affairs as well as a fully distributed process of finding errors and promoting changes. In order to support this process, Foss Electric has adopted a Japanese system for reducing the number of defects in manufacturing by enabling distributed accumulation of knowledge and experience. The *Cause and Effect Diagram with the Addition of Cards* (CEDAC) system basically consists of a large board with categories for classifying observation cards. This CEDAC board is updated by participants and regular meetings are held where the observations posted are discussed. An observation might result in a corresponding suggestion. This suggestion for change is classified according to it's current status, e.g. whether the suggestion is being tested, or whether the test performed has reached a successful result. Because the CEDAC system contains two classification structures, it reduces the complexity of distributed classification. The regular meetings, therefore, can be conducted in a more efficient manner.

1. Purpose of the CEDAC Board

The CEDAC (Cause and Effect Diagram with the Addition of Cards) Board is originally developed in Japan in the seventies (Fukuda, 1989). It has, subsequently, been adopted by Northern American and European companies. The purpose of the CEDAC System (see Figure 1) is to reduce the number of manufacturing defects through continuous improvements by enabling people to make use of their accumulated knowledge and experience. The system was introduced at Foss Electric in 1990 after representatives from the company had visited companies in Japan (for a description of Foss Electric and the S4000 Project, see Appendix A). The main purpose is to register and overcome defects, shortcomings and problems found in the production in connection with manufacturing the prototypes and the test series. This results in an improved productivity and product quality, by, in a distributed way involving the employees in solving the problems.

2. The CEDAC Board

The CEDAC System is most often materialized in a 1 x 2 m steel board which is placed on a wall at the shop floor, or being mounted on wheels (Figure 1). Each CEDAC Board contains a classification structure in the form of a “fishbone” structure. There are six different categories. The categories vary according to the particular purpose of the board. The CEDAC Boards we have observed contained the following categories:

- Blueprint errors/suggestions
- Mechanical design errors/suggestions
- Electronic design errors/suggestions
- Parts defects
- Assembly errors/suggestions
- Other

When a problem is encountered or a suggestion for improvement is found, a card describing it is attached to the board with a magnet in the appropriate category. Examples on topics are: poor and insufficient drawing specifications which could make it impossible to produce the product, inappropriate tool specifications, or unsuitable process selections. People from the different functions participate in a regular CEDAC meeting, i.e., mechanical and electronic designers, draught-persons, the project leader, process planners and a foreman. CEDAC meetings are most often held weekly. When a new product are to be assembled, CEDAC meetings can be held as often as every day.

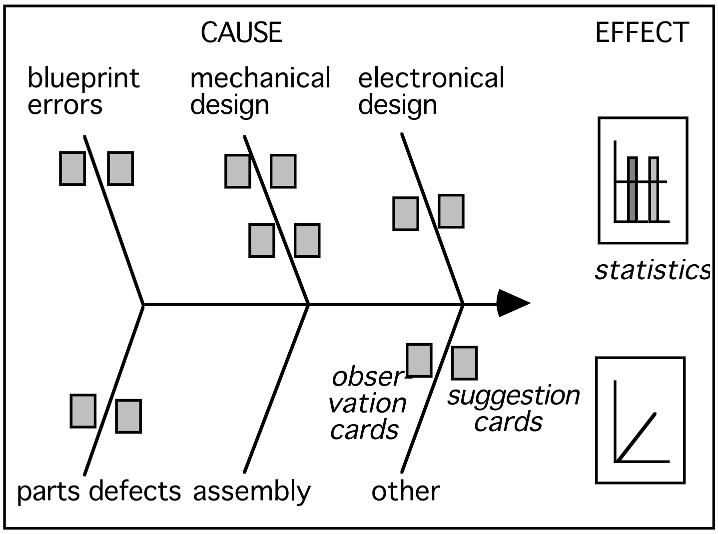

Figure 1: The CEDAC board as implemented in engineering design, process planning and production of parts for functional models and prototypes at Foss Electric.

Suggestion cards are classified in the following categories, according to the state of the suggestion in terms of deciding how to proceed further: (1) Of interest; (2)

in progress; (3) proposal not possible; (4) being tested; (5) successfully tested; and (6) the test yielded a poor result. This classification is annotated by the symbols shown in Figure 2.

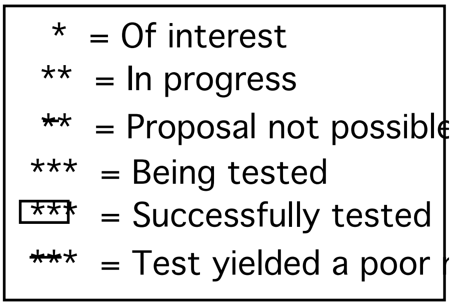

Figure 2: The six categories used to indicate status of suggestion cards on the CEDAC board.

Figure 3 shows an example of an observation card and a classified suggestion card in the mechanical design category. This example is from a project developing a small instrument which has a small eight line Liquid Crystal Display (LCD) built-in. During testing, it was observed that the particular LCD reflected sunlight, hence making it difficult to read the display. The observation card shows that the group decided to look for a LCD which has an anti-reflex coating. The suggestion card is, therefore, classified with two asterisks, indicating that testing is in progress.

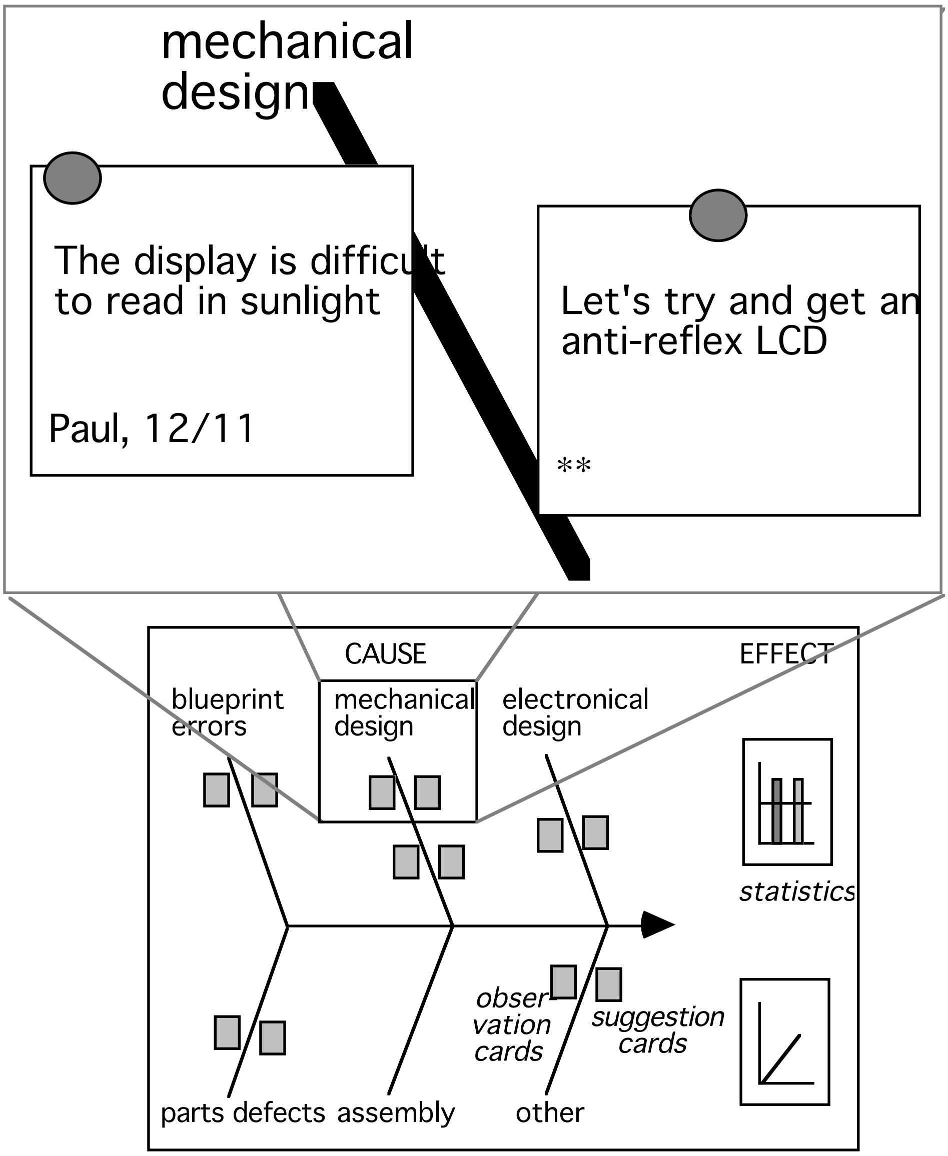

Figure 3: A simple example of an observation card and the matching suggestion card.

3. Distributed Classifications Combined with Meetings

The CEDAC System ensures that defects and good ideas for improvement are collected, negotiated and tested on a regular basis. It, hence, supports integration between the engineering design and process planning functions. The CEDAC System is not primarily meant to be an integration tool, but a tool to maintain and improve product quality. At Foss Electric, CEDAC Systems are also implemented in the assembly department and in the quality control department.

What then makes the system work? The following list contains the conditions for changes in the state of the CEDAC system to happen (the numbers in brackets refer to the corresponding state in the state-transition diagram in Figure 4):

1. The CEDAC system is basically updated by an actor finding an error or a suggestion for improvement, and hence writing an observation card. Workers on the shop floor write and classify cards on the CEDAC board describing observations made between CEDAC meetings (C1–C3). The cards are classified by attaching it on the left side of the line representing the appropriate category of the observation. If an observation is made immediately after a CEDAC meeting, a card is placed on the board, but the actor might choose to articulate the problem outside the system as well, i.e., have an informal conversation with the relevant people.
2. At a point in time determined outside the CEDAC system, a temporal event triggers the initiation of a CEDAC meeting (C4). Because the frequency of these meetings vary dependent on the type of project, the phase of the project, and perhaps also the number of cards placed on the board, the system itself is not aware of the frequency of meetings. The written organizational procedure stipulating how the system is supposed to work actually prescribes a daily CEDAC meeting at 9:00 AM. This is, however, based on the use of the CEDAC System in relation to assembly and quality control of test-series instruments, i.e., in a very limited period of the development process. When used between engineering design and process planning, the system most often leads to weekly meetings. As an example, the head of the Quality Control Department said that when they are in the first phases of testing a newly developed instrument, they have CEDAC meetings as often as each day. Furthermore, the nature of the CEDAC meetings vary over time in relation to Quality Control. In the beginning, problems related to assembly take most of the time and effort. When the major bulk of assembly problems are taken care of, the problems discussed at CEDAC meetings tend to shift towards production related problems, and lastly towards issues pertaining to the design of the instrument. The fact that these problems are discussed at a relatively late stage in the quality control process is that in order to observe problems related to the finer details of the design, the instrument must be subjected to extensive testing. Each instrument is, before being approved, both calibrated and tested by having it measure several thousands samples.
3. At the CEDAC meeting, the CEDAC foreman chooses observation cards one at the time (C5).
4. A suggestion card is, after being selected, discussed among the participants at the meeting. After being discussed, the observation card is placed on the board again (C6).
5. As a result of the discussion, a suggestion card is produced, describing the suggestion (C7).

6. The suggestion is classified, or re-classified if it's state has changed since the last CEDAC meeting due to tests (C8–C9), unless the observation and suggestion has to do with blue-print errors or errors found in the bill of materials, and therefore are straightforward to fix (C9). The classification denotes the state of the process of testing whether or not the suggestion is a viable one.
7. After being classified, the suggestion card is placed on the board again (C10).
8. When one or more categories on the CEDAC board is jammed with observation or suggestion cards, the CEDAC foreman moves old cards representing finished experiments to a folder hanging on hooks on the bottom of the CEDAC board (C12, C13). There is a folder for each of the six categories on the board.
9. Statistics on the accumulation and processing of errors and suggestions are compiled and placed on the board by the CEDAC foreman. At Foss Electric, the "Effect" part of the CEDAC System is only used in the assembly department.

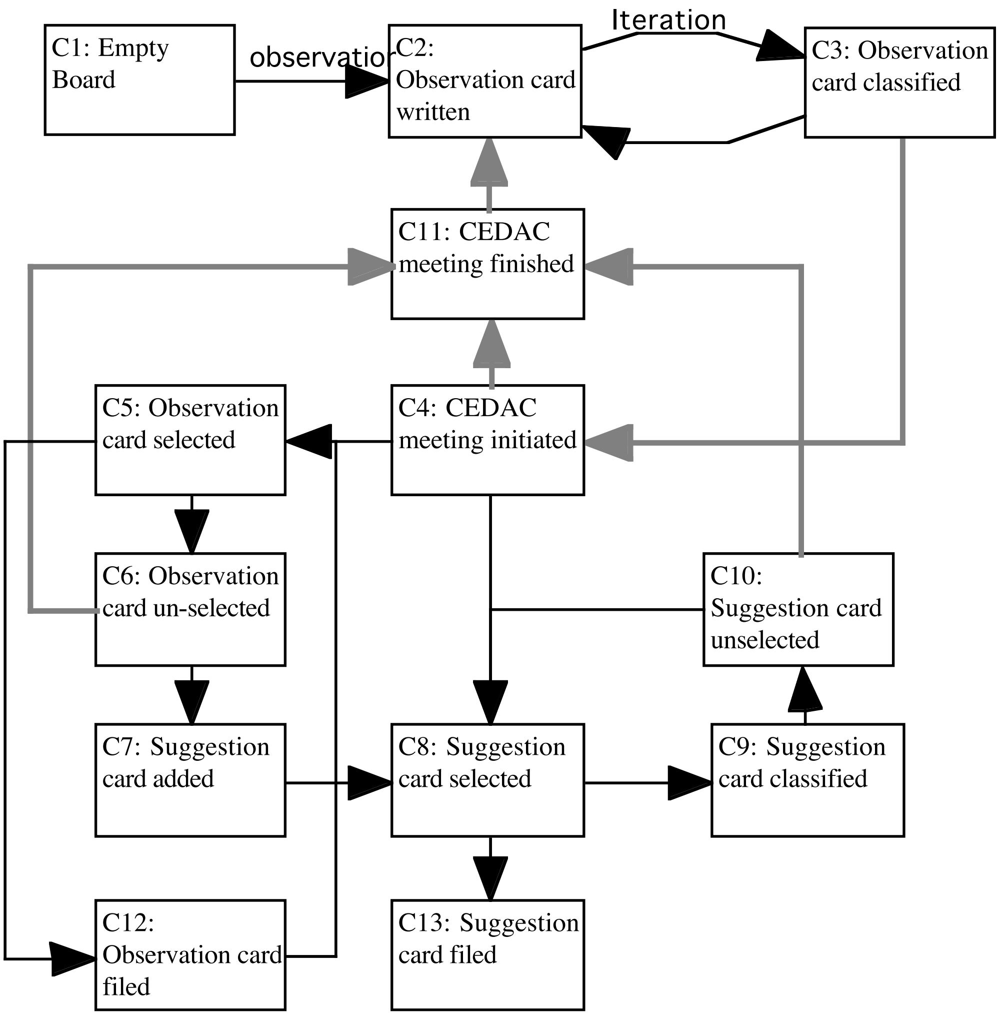

Figure 4: States and transitions in the life of a CEDAC system.

4. Making Meetings Simpler

If we interpret the CEDAC board purely in terms of an artifact reducing the complexity by stipulating and mediating articulation work, one important aspect is the objects of articulation work represented in the artifact (Schmidt et al., 1993). The CEDAC board is basically an artifact reducing complexity by providing an asynchronous communication channel and two conceptual structures of the classification scheme type. Had the board just been an ordinary notice-board with no restrictions as to whom placed what, it would only provide an easier way of performing *ad hoc* modes of interaction by providing an asynchronous communication channel. The first classification scheme is used to classify notes into types of problems and suggestions, i.e., blue-print errors, mechanical design, electronic design, part defects, assembly, and other. The second classification scheme is used to classify the state of the problem or suggestion on each card. Everyone can put up a note, but only the CEDAC foreman can symbolic show the state of the solutions by classifying the card. The board without any classification schemes would only had reduced the complexity of coordination, i.e., who is where, when. The CEDAC board, hence, reduces complexity of articulation work by combining the two conceptual structures and a symbolic representation of the field of work on notes, and because it is accompanied by an organizational procedure stipulating the division of responsibility among the different functions involved.

Figure 5 shows the symbolic references to objects of articulation work in the CEDAC System.

Nominal		**Actual**	
Objects of articulation work	**Operations with respect to objects of articulation work**	**Objects of articulation work**	**Operations with respect to objects of articulation work**
Articulation work with respect to the cooperative work arrangement			
Role		Committed actor	
Task		Activity	
Human resource		Actor-in-action	
Articulation work with respect to the field of work			
Conceptual structure (conceptualization of field of work)		State of field of work: - *Classifying observations* - *Classifying suggestions* - *Classifying state of suggestions*	classify, instantiate; direct attention to, make sense of; act on;
Informational resources		Informational resources-in-use:	
Material resources		Material resources-in-use	
Technical resources:		Technical resources-in-use	
Infrastructural resources		Infrastructural resources-in-use	

Figure 5: Classification and characterization of the CEDAC system. Text in *italics* characterizes the objects of articulation work in the CEDAC system

Acknowledgments

Henrik Borstrøm participated in performing and documenting the Foss Electric field study. Thanks to Hans H. Andersen for comments and suggestions.

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The product classification scheme

Carsten Sørensen

Risø National Laboratory

The product classification scheme developed and used at Foss Electric supports the articulation of distributed storage and retrieval of CAD models in and across development projects. The classification scheme has 16 classes and a total of approximately 340 categories. The classification structure is build mainly based on the functional properties of the components and units in the field of work, e.g., springs/dampers, optics, and transmission components. There are, however, also entries in the structure which are defined based on the structural properties of objects in the field of work, e.g., console, plate, and rod. It is used as a mixture of a paper- and computer-based social mechanism of interaction. Use of the classification scheme is not stipulated in any written procedure, the distributed activities are made according to conventions. It is, however, argued that the classification scheme itself in the form of a tree structure stipulates the articulation of distributed storage and retrieval of CAD models. The mere existence of a category stipulates that any component or unit with this functionality must be placed in the category.

1. Purpose of the Product Classification Scheme

The product classification scheme provides a means for distributed handling of storing and retrieving Computer Aided Design (CAD) models in a data management system. The CAD system was introduced at the same time as the S4000 project began, i.e., 1990 (for a description of Foss Electric and the S4000 Project, see Appendix A). One of the advantages of using CAD instead of a traditional paper-based system is an improved opportunity of reusing old components in new products. This approach is time-saving and, among other things, supports the use of standardized components. The initial purpose of the classification scheme was first of all to be able to reuse specifications of standard components produced by others. The benefits from categorizing and reusing other types of units and components will be realized after the classification scheme has been used in multiple projects. Although browsing through a file-cabinet with drawings is a time-consuming task, it is possible. When work is based on CAD models stored in a database, browsing is not a feasible strategy for reuse of existing specifications. If, however, CAD models are categorized, existing specifications can more easily be retrieved. Hence, in relation to introducing CAD, the company developed a classification scheme capturing components and units for all instruments produced. Before introducing CAD workstations, Foss Electric used a much less rigid and elaborate classification system.

The classification scheme (Figure 1) was developed by 6–7 people. They each put about two weeks of work into the task, some of it in weekends. The group started by agreeing on the 16 main classes. From thereon they worked on down through a hierarchy. When arriving at the most detailed level of categorization for each class, they delegated the work of specifying the record format in the data management system to individual members of the group (see Figure 2). The work was characterized by fierce discussions and negotiations on which classes, categories, sub-categories, and sub-sub-categories the classification scheme should contain. The project leader of the S4000 project, who participated in the defining the scheme, states that given 6–7 other people from Foss Electric, the classification scheme would probably look different.

2. The Product Classification Scheme

The classification scheme is partly paper-based and partly computer supported, and the use of it is not stipulated in an organizational procedure, but only by conventions. The classification is most often determined based on consulting a A3 size scheme which the draught-person has on the desk. The classification is then entered into the data management system by selecting from a list in a menu on the CAD system. Here, all the classes, categories, sub-categories and sub-sub-categories in the classification scheme are alphabetically ordered. The paper-based scheme is a print of the classification scheme specified in the database. It is ordered in a tree-structure with classes, categories, sub-categories, and sub-sub-categories. There are 16 classes, and approximately 340 different categories, sub-categories, and sub-sub-categories. As an example, class number 5 is hydraulic and pneumatic components, which has 11 categories. One of these is valves, which has 6 sub-categories and no sub-sub-categories (see Figure 1).

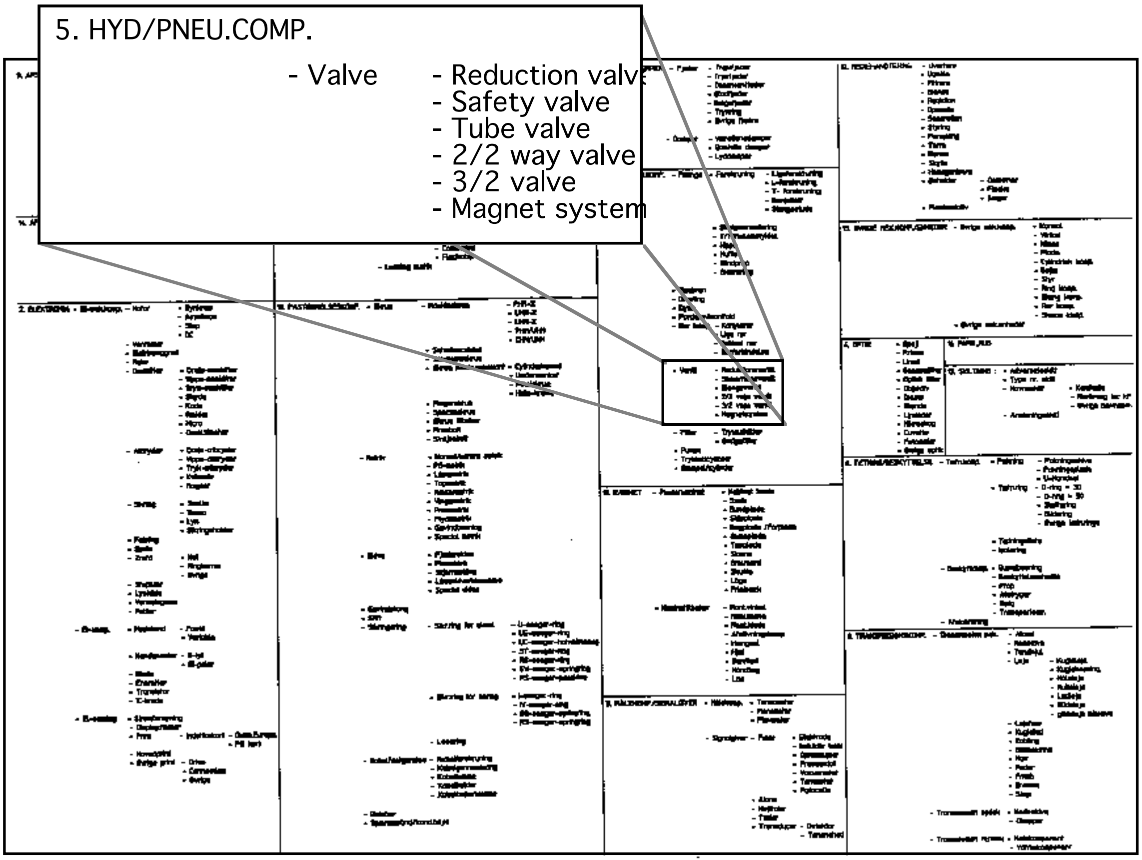

Figure 1: The product classification scheme — the different sub-categories belonging to the category of valves, which are of the class hydraulic and pneumatic components.

At the most detailed level, each sub- or sub-sub category is specified in the data management system according to the predefined database records. Figure 2 illustrates the format of the record describing objects of the type “lens”.

Class: Optics						Initials: N.N.
Category: Lens						
Name	**Field type**	**Length**	**Right/Left**	**Priority (1–12)**	**Example**	**Sorting order**
Name	Character	25	L	1	Lens	1
Part number	Character	12	R	2	12345678.KLI	
COPICS name	Character	12	L	last		
Material	Character	20	L	8	Glass BK7	
Project #	Numeric	5	-	9	29510	
Comment	Character	50	L	10		
Form	Character	12	L	3	Plane/convex	2
Outer radius	Numeric decimal	3.1	R	5	28.5	4
Center thickness	Numeric decimal	2.1	R	6	3.5	5
Edge thickness	Numeric. decimal	2.1	R	7	1.5	6
Focal length	Numeric. decimal	3.1	R	4	12.5	3

Figure 2: This form illustrates how records for the data management system is defined. This example shows the fields in the record for specifying the category “lenses” in the “optics” class. Note that this particular class does not have any sub-sub categories.

3. Classification, Retrieval, and Modification

When a CAD model for a component has been specified, the draught-person classifies it according to the classification scheme. The classification is an extra attribute in the data management system (see figure 2). The categories are from time to time modified, and new categories are added in order for the scheme to represent the type and function of components specified. Changes to the scheme are results of negotiations between designers and draught-persons at designated meetings. The classes and categories in the scheme are based on a mix of functional and geometrical properties of components and units. The classification structure is build mainly based on the functional properties of the components and units in the field of work, e.g., springs/dampers, optics, and transmission components. There are, however, also entries in the structure which are defined based on the structural properties of objects in the field of work. There is, for example, a class named *“other mechanical components and units”* containing categories such as: console, plate, cylindrical component, tube component, and rod. This gives the draught-person a means of classifying very irregular components, which otherwise would have been impossible to fit into the scheme.

Figure 3 shows a diagram of the basic states and transitions involved in classifying a CAD model for a particular component or unit. At first the CAD model is not classified (S1). Then a category, a class, sub-class, and sub-sub-class have been selected (S2–S5). Then the form is filled in (S6), and the CAD model is classified (S7). This brings the classification scheme back to the initial state (S1).

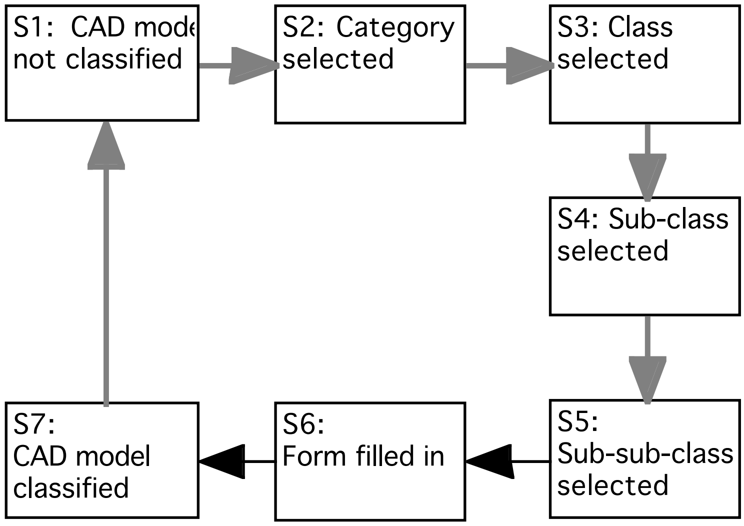

Figure 3: A state-transition diagram illustrating how the product classification scheme is used for distributed classification of CAD models and entering the data-form (shown in Figure 2) in order to store the model in the product database.

The retrieval of CAD models from the data-management system using the product classification scheme involves the following states and transitions (see Figure 4): Initially no CAD model has been retrieved (R1). The tree structure is traversed selecting a category, a class, a sub-class, and a sub-sub class (R2–R5). This can lead to one of two states. Either the appropriate CAD model is found or it is not. If it is found (R6), the initial state is reached and a new CAD model can be retrieved (R1). If it is not found, the same state is reached and a new search-round can begin (R1).

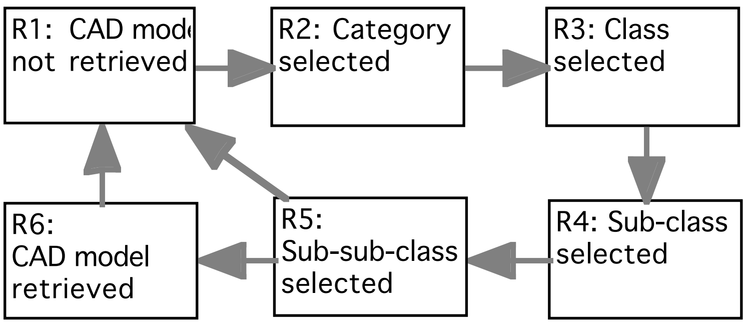

Figure 4: A state-transition diagram illustrating use of the product classification scheme for distributed retrieval of CAD models in the product database at Foss Electric.

The two previous figures illustrated the basic states and transitions involved in distributed storage and retrieval of CAD models using the classification scheme. Figure 5 shows the states and transitions when the classification scheme is modified. Contrary to the two previous activities, modification of the classification scheme itself is not supported by any artifact. When a change has been negotiated and decided at planned or informal meetings, each person makes the changes with a pen on their own paper copy of the classification scheme and one of them updates the computer-based classification scheme. For each level in the tree structure, a category or class can be selected (M1, M5, M9). It can then be either renamed (M2, M6, M10), deleted (M3, M7, M11) or a new one can be added (M4, M8, M12). Selection of a class on the next level can either be made without making changes on the previous level, or from each of the states where a change has been made. Furthermore, from any state of having updated the classification scheme, the initial state can be reached.

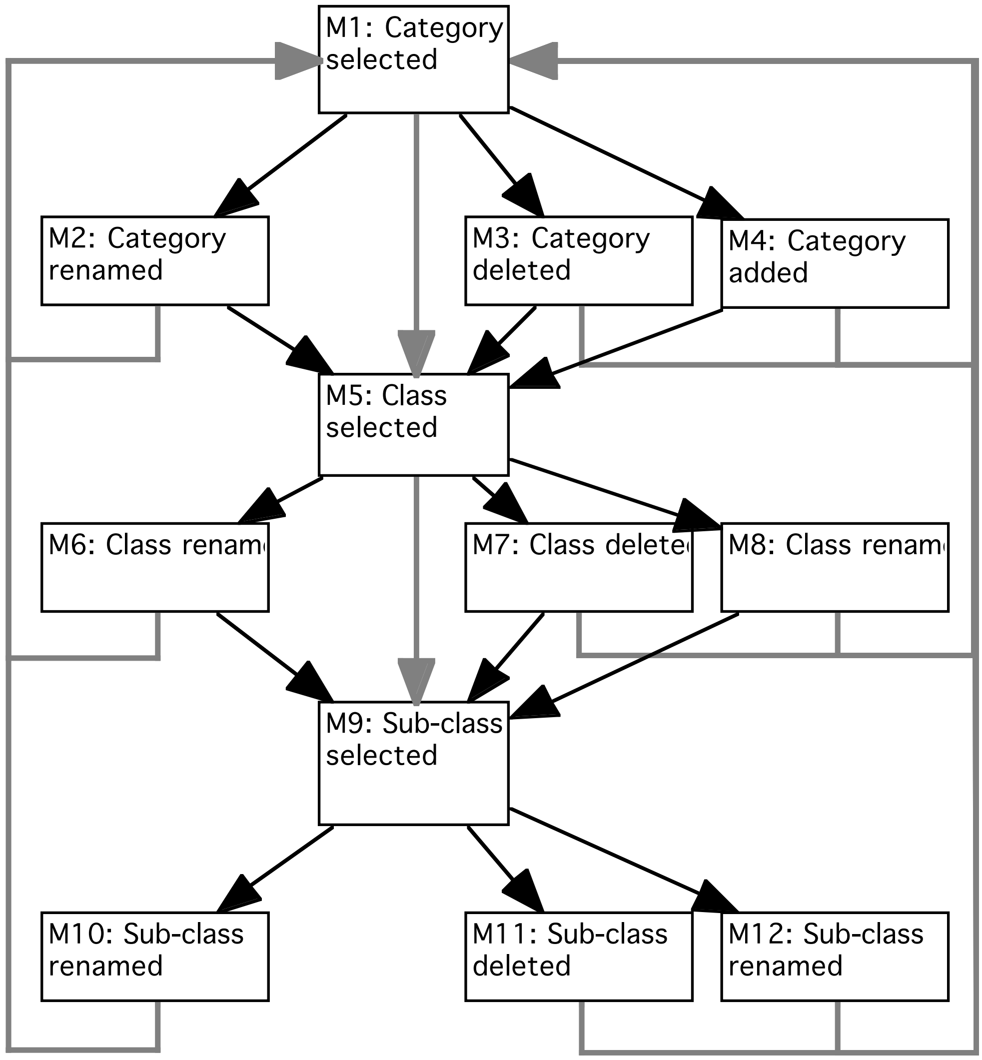

Figure 5: A state-transition diagram illustrating the protocol for modification of the product classification scheme at Foss Electric. States and transitions for sub-sub-classes are not included since they are structurally identical to the previous levels.

4. Stipulating the Articulation of Distributed Activities

The product classification scheme reduces complexity of articulation work solely by providing a conceptual structure (Schmidt et al., 1993) making it possible for draught-persons and engineering designers to perform distributed storing and retrieval of CAD models. It reflects a common standard for categorization of the components and units in any instrument produced at Foss Electric. The 16 classes and about 340 categories can be viewed as the negotiated order of how an instrument can be formally described. It is enforcing a standardized format for filing and retrieving CAD models. In that sense, the classification structure *stipulates* the distributed cooperative task of placing the CAD models at the appropriate place. The artifact does not, like in the case of the International Classification of Diseases (Bowker and Star, 1991) provide any explicit procedures for how this task should be fulfilled. The nature of the classification scheme, identifying the basic components of any instrument developed and manufactured at Foss Electric does, however, provide a very forceful structure determining, at least roughly, where a given specification should be placed. There are, of course, situations when the draught person are in serious doubts as to where exactly to place a model. Also, engineering designers are at times in doubt about where to look for a model. This, amongst others, reflects that the classification structure is a dynamic entity reflecting a dynamic field of work. Also, the classification scheme is defined, based on a mixture of criteria. The primary criteria used for defining the categories is function, e.g. optics and hydraulic/pneumatic components. In order for the scheme to properly describe the diversity of objects to be classified, form is also sometimes a defining criteria, e.g. the class miscellaneous components and units which contains categories such as: block, plate, console, and rod. Most of the situations where there are uncertainty about how to classify a model the component in question is a very specialized one where the functionality is not obvious. In these cases, components are frequently classified according to form instead of function. Viewed from the perspective of the basic purpose of the classification scheme, this is actually not a problem. The classification scheme serves the purpose of enabling distributed storage and retrieval of CAD models in order to reuse specifications. The primary reason for wanting to reuse specifications is that a certain amount of components in the instruments developed are purchased standard components, or components made specially for Foss Electric, but are used in several instruments. The odd components which are specific to a particular instrument, and which might be difficult to classify, will probably not be in great demand in other projects.

New components and units are designed all the time, and it is often difficult for the draught-person to perform the classification. This does, however, not result in constant changes to the classification scheme. Because the scheme is used by many different people, changes have to be negotiated. As in the case of the International Classification of Diseases re-interpreted by Schmidt (1993), use and management of the product classification scheme can be characterized as a struggle of carefully finding *"the appropriate level of ambiguity"*.

Figure 6 provides a classification of the objects of articulation work in the product classification scheme viewed as a social mechanism of interaction.

Nominal		**Actual**	
Objects of articulation work	**Operations with respect to objects of articulation work**	**Objects of articulation work**	**Operations with respect to objects of articulation work**
Articulation work with respect to the cooperative work arrangement			
Role		Committed actor	
Task		<u>Activity:</u> - *Classifying and retrieving CAD models*	initiate [Committed actor]; done by [Actor-in-action]; realize [Task]; make publicly perceptible, monitor, be aware of; explain, question;
Human resource		Actor-in-action	
Articulation work with respect to the field of work			
Conceptual structure (conceptualization of field of work)		<u>State of field of work:</u> - *CAD models* - *Part name* - *Part number* - *Miscellaneous part properties* - *Project number*	classify, instantiate; direct attention to, make sense of; act on;
Informational resources		Informational resources-in-use:	
<u>Material resources:</u> - *Material*	categorize; locate, procure, allocate, reserve;	Material resources-in-use	
<u>Technical resources:</u> - *CAD models* - *COPICS name*	categorize; locate, procure, reserve;	Technical resources-in-use	
Infrastructural resources		Infrastructural resources-in-use	

Figure 6: Classification and characterization of the symbolic references and functions in the Product Classification Scheme (PCS). Most of the objects listed can be found in the form shown in Figure 2.

Acknowledgments

Henrik Borstrøm participated in performing and documenting the Foss Electric field study. Thanks to Kjeld Schmidt for putting up with me in our numerous discussions on what classification schemes actually do in terms of stipulating articulation work. Also, thanks to Hans H. Andersen for comments and suggestions.

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The fault report form — Mechanisms of interaction in design and development project work

James Pycock and Wes Sharrock

Manchester University

This paper consists of three main sections. The first discusses the ethnographic approach we have taken to analysing and describing work, courses of action, their organisational context, their relationship to plans and projections and, finally, to those mechanisms of interaction evident in work situations.

The second section details those representations and mechanisms of interaction (e.g. 'Fault Report Forms') found to be at play in the organisation of a design and development project we studied. Our report also describes some of the working practices associated with these mechanisms of interaction.

The third section presents a discussion of aspects of the field study using notions of the 'social distribution of knowledge' taken from the work of Schutz. In this section we address, among other topics, how different groups within the project come together to interpret or 'read' the Fault Report Forms and the information about the field of work that they represent. We also discuss some how some of the practices of the 'writers' and the 'readers' of these forms are related.

1. Introduction

Today's business environment is perceived as rewarding speed, flexibility, quality, timeliness, etc. in organisations. Despite the 'hype' that surrounds such statements, serious consideration is being given not only to the products developed by companies but to the means and processes by which such goods are produced (perhaps especially in service industries such as banking were products and processes are closely linked). The production processes are, of course, generally cases of cooperative work and often in the large scale. Changes to production processes aimed at reducing manufacturing time, responding better to customer requirements and market demands, delivering quality products 'on demand', ordering parts 'just in time', and so are seen to place demands upon the coordination and articulation of cooperative working. For example, introducing parallelism or concurrency in a work process introduces a need to coordinate, monitor progress, check dependencies, be aware of 'knock-on' effects of schedule slips, and the like. That is such organisation of work introduces complex *articulation* tasks - coordinating, scheduling, meshing, interrelating, integrating, etc. - the distributed cooperative activities.

As was described in COMIC-D3.1 much research orientated towards supporting such cooperative work has:

> "focused on providing enhanced means of communication, either in order to enable actors to cooperate more effectively and efficiently in spite of geographical distance, or in order to widen the repertoire of communication facilities" (page 6)

Yet the Deliverable goes on to note that:

> "with the complex work environments of modern industrial and administrative organizations, the problems of articulating distributed activities are at a different order of complexity. The everyday social and communication skills are far from sufficient for articulating the cooperative efforts of hundreds or thousands of actors engaged in myriads of complex interdependent activities, perhaps concurrently, intermittently, or indefinitely" (page 6)

The Deliverable suggests that:

> "In such settings, the articulation of the distributed activities of cooperative work requires a certain class of symbolic artifacts that stipulate and mediate articulation work and thereby reduce the complexity of articulation work. We have chosen to call these artifacts 'mechanisms of interaction'. A mechanism of interaction can be defined as a device for reducing the complexity of articulating distributed activities of large cooperative ensembles by *stipulating and mediating* the articulation of the distributed activities." (page 6)

Hence our concern here is to understand the role of mechanisms of interaction (MOI) in cooperative work and to move towards providing a conceptual foundation to inform the requirements such MOIs must meet (with a view to developing computational notations as a means for incorporating MOIs in CSCW applications). As the first Deliverable observed:

> Such artifacts have been in use for centuries — in the form of catalogues, time tables, routing schemas, kanban systems, and so on. Now, given the infinite versatility of computer systems, it is most likely — and this is the underlying contention of the work within Strand 3 of COMIC — that computer-based mechanisms of interaction can provide a degree of visibility and flexibility to mechanisms of interaction that was unthinkable with previous technologies, typically based on inscriptions on paper or cardboard.

Indeed it is very much the case that we do not have to search for MOIs in the work place, they confront us almost immediately. However, somewhat harder, we suggest, is to understand their full meaning in some situation, at some time and, importantly, for those concerned with the work and the using of the MOI.

We have seen in Strand 1 how there is a considerable plurality of ways in which the analysis of organisational life can be undertaken. There is no unique starting point from which inquiry into the workings of organisations need be launched, no set of assumptions which it must definitively make nor any agreed set of standards which it must satisfy. While on-going work in Strand 1 explores the consequences of this multiplicity, in this report we are interested in outlining and following through one way of investigating organisations, one which, in acknowledgment that 'organisations' typically stands for work organisations, pays its attention to the actual way that work activities are organised and, in particular, the mechanisms of interaction that are used in the scheduling, meshing, planning and the like, of distributed cooperative work activities.

This report describes an ethnographic approach to understanding work and the mechanisms of interaction used in its articulation. The precepts of this ethnographic approach have been described in detail elsewhere in COMIC (LANCS-2-4) but we shall outline how several key perspectives adopted by this approach determine the examinations we make of mechanisms of interaction, such as plans in project work.

We shall then consider a case study undertaken by Wes Sharrock and others of mechanisms of interaction in a design and development project. This is very much a first attempt at considering some of our field studies in terms of the conceptual work developed so far in Strand 3. Additionally just as Strand 3 work seeks to sensitize analysts to aspects of primary importance to the design of CSCW systems, so the second purpose of reports such as this one is to inform the development of that framework with detailed observations of MOIs in actual use. Much work remains in working through these dual implications.

2. An Ethnographic Approach

Somehow the members of an organisation get through their daily rounds, *somehow* they execute the responsibilities and carry the burdens of their positions within the social order, they turn up for work, they serve out the shift, they go on vacations and engage in leisure pursuits, and in multifarious ways these assorted affairs of the social order get done. However, it is not enough for us that the members of an organisation can do ‘air traffic control’, ‘make the trains run’, ‘match invoices’, ‘build software’, ‘design printers’, and so on. Rather it is the detailed ways in which these activities are undertaken, stipulated and mediated that is the focus of examination for us.

The distinctiveness of our approach (developing from a Schutz/ Garfinkel initiative (Schutz 1964, Garfinkel 1967)), is that it encourages the opening up of the ‘somehow’ and ‘whatever’ clauses to examination in a systematic way. That the members of the organisation do somehow conduct the affairs and cooperative activities of their daily life, that they ‘manage’ the daily rounds of the office, the home, the traffic, and so forth seems as much a bone fide topic for sociological investigation as any other, but one which is, given the preoccupations which dominate sociological work, an extensively neglected one. Central to such an investigation is a concern for MOIs because when we look at these situations we see a huge number of heterogenous MOIs in daily use (plans, schedules, timetables, project management tools, and so on) and they appear to *somehow* play a vital role in the articulation of cooperative activities, in getting the work done.

Deliverable 3-1 noted how a particular type of this ‘somehow clause’ has been carried over into the development of computer support for work tasks and is evident in the design methodologies for developing such computer support tools:

"In the design of conventional computer-based systems for work settings the core issues have been to develop effective computational models of pertinent structures and processes in the field of work (data flows, conceptual schemes, knowledge representations) and adequate modes of presenting and accessing these structures and processes (user interface, functionality). While these systems, more often than not, were used in cooperative work settings and even, as in the case of systems that are part of the organizational infrastructure, were used by multiple users (e.g., database systems), the issue of supporting the articulation of cooperative work by means of such systems has not been addressed directly and systematically, as an issue in its own right. If the underlying model of the structures and processes in the field of work was 'valid', it was assumed that the articulation of the distributed activities was managed 'somehow'. It was certainly not a problem for the designer or the analyst.[48]

48 A similar point was made very early in CSCW by Anatol Holt: "Whatever has to do with task interdependence — *coordination* — is left to the users to manage as best they can, by means of shared databases, telephone calls, electronic mail, files to which multiple users have access, or whatever ad hoc means will serve." (Holt, 1985).

" (page 21)

It is just these types of 'somehows' which we set out to empirically examine in situations of use for MOIs.

2.1. An ethnographic view of work

Ethnography is concerned to characterise the way in which we experience the social world, and to recognised that the analysis must begin with its location in a 'here and now'. It is concerned with the ordering properties of activities similarly appreciated i.e. that the conduct of action is; likewise, organised from some 'here and now'. Additionally it is concerned with understanding the carrying out of courses-of-action, with examining the ways in which they are organised, or, as we will sometimes say, 'managed' , in and over their course. The analysis is therefore one of 'social action in real time,' 'analysis from the midst of things', all of which focus attention upon the way in which the activity is being done and the way symbolic artifacts are being used.

A course of action, something which is characteristically a temporally extended phenomenon, and mention of the 'midst of things' means that at any moment the activity is somewhere in its course. The notions of 'the midst of things' and of 'real time' mandate one further feature of our approach, which is that it requires that we give prominence to the 'time structure' of the action. A course of action is often undertaken without knowing how it will turn out - this may be especially so in the case of some design and development projects developing new systems and equipment/products etc. where to a certain extent the course of action has never been done before.

The course of action may be directed toward an outcome, is undertaken to deliver that outcome, but that it will deliver the outcome to which it is directed is not something about which there can be any assurance even as the course of action is initiated and pursued. Similarly mechanisms of interaction used to stipulate and mediate the cooperative activities in the work must be related to the 'open ended' nature of the course of action and as analysts we must attend to the actual features MOIs and their usage in these situations, not just idealisations.

In terms of the carrying out of the course of action, whether it will turn out as projected is something which, at certain moments in its course, will only remain to be seen, where the specific yield of the activity for those undertaking it is as yet undetermined (though it may later in the course become apparent that the outcome will be attained or that it is not going to be). The analyst of social activities often has a 'privilege' which is denied to those who carry out the affairs being analysed, which is to know how things turned out, to be able to analyse the course of action in the light of its actual outcome. However, if one is concerned with the way in which the course of action is carried out, then the 'benefit of hindsight' may be a dubious one, for reliance upon it may obscure the very thing that one intends to examine, which is the extent to which the course of the action can be anticipated from within its course and how the articulation of the work reacts to this.

2.1.1. The variably predestined character of courses of action

The investigation of the ways in which those who carry out the courses of action 'build' those courses, as they go along, and the tools, technologies and MOIs that they use in this building work, is the project which most basically underlies our approach. Before we turn to the topic of work specifically, there are perhaps some implications which may be inappropriately ascribed to the line of thought we have sketched, and which we need, and can usefully, disavow. The idea that those involved in a course of action are building it as 'it goes along' may be taken to suggest that we are saying that nothing is, so to speak, predetermined, that all of social life is an utter improvisation, but this is no suggestion that our remarks carry. The extent to which the conclusion of a course of action is a 'foregone conclusion' is a variable feature of courses of action. Some lines of action provide, as we will describe below, 'sure fire' ways, ones that assuredly deliver their intended product, whilst others are of varying degrees of reliability and some acknowledged to be risky indeed. Yet other courses of action are undertaken to see where they lead, in what they result, where prior to the outcome, it is for no one to say what their yield will be. The extent to which the course can be projected or anticipated is a feature of it, and the extent to which it can be so is something to which those who carry it out attend. That one is, in carrying out a course of action, following in steps that have been taken many times before is, of course, and which means, of course, that one can have a most definite sense of just what remains to be done, a clear anticipation of the specific steps outstanding, but this is just to talk about one of the ways in which a course of action can be 'built' for, of course, very different kinds of courses of action are built.

We do not argue over whether courses of action are in general effectively foretold or underdetermined ours is simply a way of characterising the organisation of different courses of action, of contrasting that which crosses, so to speak, familiar territory, with that which enters into the unknown, that which involves doing what the doers have done uncountable many times before against that which is pretty much unprecedented for them.

Our own insistence is upon the variably 'predestined' character of courses of action in which the action whose outcome is inexorable contrasts, in our characterisation, with that whose course cannot be anticipated, and our characterisation is not of our determination of the reliability or otherwise of these lines of actions, but of the status that they have in the hands of their perpetrators. In other words, we are not saying, here is a course of action, or here is a stipulation of the cooperative interactions, which is undertaken and it is a 'sure fire' means such that we can say for certain that it will come out with this conclusion, however those carrying the course through estimate its chances of success. Ours is, rather, a characterisation of the estimation of the chances of success which those carrying out the activity make, and to say it is a 'sure fire' means is to say it is undertaken as a familiar and reliable sequence of action by its perpetrators, an activity done in the assurance that it will engender a required result.

2.1.2. The 'What?', 'How?', 'When?' questions of doing

We are concerned to understand how activities are carried out but to understand them in the terms in which the work confronts those who carry out that work, as something to do, something that confronts them to be done, which they are in the course of doing, or that they have already done, and the filling out of this involves, of course, addressing the question of what it is that is to be done, is being done or has been done (or noticeably not been done) and how it is that whatever it is that is to be done, is being done, or has been done is to be accomplished and when activities should be done or have been completed. We are concerned with work as a 'lived reality' and with and with giving a more 'in the round' portrayal of the character of the work as something to do than is usually given in the literature.

What that 'lived reality' will be is, for us, an *empirical* matter. As one example, while an immense interest in work is pursued across the social sciences in terms of notions of 'job satisfaction'. We consider such an interest as 'one sided' one. This is not, however, we hasten to add, any kind of denunciation of it, for we do not reject a concern with 'job satisfaction' but neither do we make it a focal feature of our concerns. In the approach we take it treated as a phenomenon amongst others, as one factor among many others, as something which may arise in and have importance for the carrying out of the work but which is one amongst the innumerable relevances which inform the a course of work activity. Thus, again, we here state that our concern is with the determination of the relevances that those who do the work see, the considerations that are cogent to the carrying out of the work-in-hand, the matters that are now properly, appropriately, even perhaps necessarily attended to in respect of the initiation of the work -about-to-begin or in the further conduct of the-work-already-under way. It may be that dis-satisfaction with work can be pervasive, that work may be carried out in such a way as to express the fact that it is being done with no satisfaction, for example, but that its perpetrators are dissatisfied with the terms and conditions of their work may be something which is only spasmodically manifest in what they do. 'Job satisfaction' would be of interest to us in this way, as an observable feature of the way in which the job was done. Someone carrying out a course of work can carry that course out as one in a way which makes it, for example, a matter that 'I am doing this work but quite honestly could not care less whether it gets done and certainly can't be expected to look like I'm interested in it while I'm doing it' , or as 'Oh God, I don't have to break off this to go to another time consuming, boring and, so far as I can see, quite pointless meeting where they only want me to attend to make up the numbers '

It can , of course, be that the organisation of a meeting can be conducted, in part with respect to the 'management' of the fact that those present would rather be anywhere else than at it, that the organising of the meeting is to so-licit/engender involvement, participation and to deliver tangible satisfactions, a sense that something has been achieved. In this way, our concerns are with the characterisation of the organisation of activities and not of supposed 'subjective' states.

2.1.3. Doing and describing work-in-an-organisation

A further elucidation refers to the relationship between the 'courses of action' and the 'wider setting' or organisational context within which these courses of action are situated. Talk of 'situations' and of 'local organisation' terms which are sometimes used to sloganise concerns comparable to ours perhaps enhance the risk of confusion here. If we are attending to specific courses of action, ones which are, as we have said, conceived in terms of their 'here and now' location relative to the experience of their perpetrators, then are we not talking about an understanding which is confined only to the specific, immediate, local situation within which the activity is 'situated', a situation which is bounded by those of us who are here, together, at this particular moment? But is social life not much wider than this? Is what we are doing in this 'here and now' not part of a much more encompassing, long lasting, widespread venture something which we cannot comprehend merely in terms of the immediate situation and the actions conducted in it ? Are not the tasks we are doing 'somehow' related to others we, or others, are doing, will do or have done?

Here, however, we are being offered a choice that is a spurious one, as though the adequate *characterisation* of the activities being done, of the work they are carrying out, could be provided without reference to the venture within which these activities were a part, without comprehension of the fact that these activities comprise operations in a protracted and distributed programme of operations. Garfinkel and his colleagues report, for example, upon the work which a group of astronomers perform as they optically discover a pulsar. It is not an incidental feature of that work that it is done by its perpetrators *as a* matter of finding something that an entire discipline has been (so to speak) looking for, that the moment at which they make their discovery is one which advances the discipline. In a more mundane fashion, it is not, of course, the case that those on a design and development project do their work as a set of momentary tasks without any awareness of the fact that these are tasks-in-a-project and that their work on them is working-an-organisation, without the place on these tasks within the course of the project-as-a-whole or within-the-schemes-of-the-organisation having specific relevances to their organisation.

Thus, for example, it might be that those engaged in a problem solving activity proceed in a certain way to organise their problem-solving just because this is the organisationally standardised way in which they are mandated to work on problems. To ignore the extent to which their work is *inter alia* done as work which carries out the current steps in an extended sequence of operations, which is directed toward a currently remote objective, which is done in conjunction with others not now present in the situation, is being carried out subject to the demands of schedules and so forth would be to give an extraordinarily impoverished characterisation of those activities, one which would (to borrow from Gilbert Ryle's terminology) only 'thinly' characterise the actual phenomena we were dealing with, divesting them of the characteristics which they actually possess. Hence, it is the most elementary supposition of our study that the work it examines is (through and through) work-in-organisations, that it is as work-on-one-of-this-organisation's-projects that it is conducted and carried through, but, the respects in which facts of the organisation's life figure in activities in any here and now will be a distributed matter, their relevance varying according to the situation.

MOIs are of course, and as we shall see, often crucially involved in making visible across the distributed work the 'bigger picture' of the 'wider setting' and conveying an understanding of what others are doing, what needs to be done, what remains to be done, how the parts fit together and how the cooperative work is articulated.

2.2. An ethnographic view of plans in project work

Before going onto the details of the case studied let us just say a few words about plans as mechanisms of interaction designed to project, stipulate and mediate future courses of action. COMIC has already discussed a number of aspects of plans, their status and, as part of a central issue in CSCW, their relation to actual situated actions (see for example Deliverable 2.1 and COMIC-MAN-1-7). We have a number of further points to make based on studies of a number of engineering design and development projects (see for example Anderson et al 1993) and relevant to the topics of this report.

2.2.1. Recipient designed

The construction of plans in actual practice do not typically involve the supposition that everything must be spelled out after the fashion of a purportedly scientific model with nothing left implicit. Plans in practical life are characteristically 'recipient designed', spelled out more or less fully depending on the extent to which those who are to follow them are, for example, familiar with the circumstances in which they are to follow them.

(A further aspect of this 'recipient designed' nature of plans, and indeed mechanisms of interaction in general, is that they assume in their structure, design, format, and the like, certain recipient knowledge that will allow the MOI to be readable and intelligible. We discuss this later in the report and also highlight the social distribution of this knowledge and practices of sharing it).

2.2.2. Planning for contingencies

Nor does the making of plans indicate any expectation that the course of action specified in them will, of necessity, follow through. Plans often include 'fail safe' devices to cope with situations where things go badly awry, and arrangements to allow for the adaptation of the plan to exceptions, unforeseen circumstances - even its extensive revision - and so forth, as well as mechanisms to oversee the implementation of the plan and to enforce its requirements.

Those who undertake the planning of such projects are not naïve with respect to the fact that courses of activity will not necessarily or in every fine detail follow those which they specify in their plans. To concoct and formulate their plan the planners depend upon their typified conceptions of how courses of action are carried out, or upon the presumed grasp that others on the project will have of how things are to be done. They are well aware that the efficacy of methods is itself variable, and that the ways in which those in the organisation work varies from the deployment of 'sure fire' techniques to the dependence upon techniques which are less than wholly reliable. Even the more dependable techniques may require skill and experience in their application.

In working out the sequence of operations that a project is to follow, it is often appreciated that the project may deviate from the plan because of unforeseen problems, unplanned for contingencies, etc. It is routinely accepted that though there are detectable areas of risk, there is also every prospect of problems arising which could not be foreseen. The employment of methods of 'risk analysis' might enable the identification of the most problematical phases of development and might permit, for example, their treatment at an early stage in the process. But 'risk analysis' is not supposed to provide a guaranteed way of recognising all the risks that a project runs. The very operation which one might suppose in advance is the least problematic might turn out to be the one that gives all the trouble.

2.2.3. Guesswork

The planning of such projects involves seeking to determine what will have to be done and, crucially, how long it will take to do whatever needs to be done - by whom and with what resources also requires factoring into the equation. The most effective way to estimate how long a particular activity will take is to know how long it has taken previously, and to assume that it will, other things being equal, take the same amount of time again. (Hence, the motivation to get on the record details about past projects, their problems and delays). However, given that design and development work consists in doing many things which have not been done before, the attempt to determine how long they will take is often a matter of outright guesswork.

Many of the decisions which have to be made are, further, judgments as to how much is enough. How much is enough is something which can often be determined only retrospectively. How much detail one needs to go into is a question which cannot be given a formulaic answer. Nonetheless, though the question 'how much is enough' can only be confidently answered with hindsight decisions cannot await on hindsight but *must* be made.

The scheduling plan that is made is not, however, typically so tight that any problems will throw the entire plan off schedule. None of the projects we have studied in the past was set up on an the assumption that everything would 'go right first time' but the more usual schedule allows for the prospect that there will be problems and delays in carrying through a task. The plans provided a set of targets and the meeting of those targets is regarded as a relatively high priority matter, not least to avoid the consequences of failing to meet them. As target dates approached, sole priority may be given to making efforts to meet them, and in some cases, this would involve doing things merely and solely to make the target (such as providing new software releases though the work properly preparatory for them had not been done) in order that other dependent schedules were not effected. 'Schedule slips' were often a preoccupation and every effort was made to avoid them though they would, nonetheless, take place and the project timetable would be revised.

2.2.4. Planing in organisational contexts

Typically, within organisations a given project is one among a number. Over its course it will involve a varying number of individuals and vary in the kind of work to be done and the mix of skills required to do it. A projection of the articulation of work is required to determine the nature of the team required and to ensure the availability of appropriate members at the point in time. A basic objective is often to ensure that design and development staff were kept continuously employed whilst also ensuring that they can be rotated from project to project as they are needed. Projects often have to make specific demands for the time and the scheduling they will require from particular engineers in order that the effort of those engineers can be optimally allocated amongst competing teams. For example in one case we have studied in the past a system known as 'matrix management' was used, in which individuals were members of both functional departments and project teams and, therefore members of potentially more than one team. In this way plans and mechanisms of interaction may serve the dual purposes of coordinating the allocation or sharing of people and resources between projects within an organisation, and also articulating the cooperative working to take place within the bounds of a project itself.

2.3. Making the plan work - resolving competing demands

Finally we want to make two primary points about making the stipulations and mediations of mechanisms of interaction, such as plans, actually work in these projects. Firstly, that planning is itself a satisficing activity and, secondly, that the planning itself often involves the passing on of issues to those doing the work. This may be in the form of unresolved problems, judgments and prescriptions about the work.

Planning cooperative work and the articulation and coordination of people, projects and resources, as we have encountered it, is one more of the organisation's tasks, and, of course, is itself subject to the same constraints as other parts of organisations, with respect to the assignment of tasks, scarcity of resources and so forth, and it is, itself, as mentioned, subject to satisficing treatment. How much time is to be invested in the plan, how much information gathering, how much working out of the project are all questions which can be answered in terms of the effort required - and whether further effort will be worthwhile, more worthwhile than other things that can be done. The planning which we have studied has not sought to provide the detailed prescriptions of the precise operations to be followed by those working on the project and under the auspices of its planning. The plans have served more as a specification of requirements, the enumeration of things that must be achieved, and, very importantly, by when rather than as a detailing of how those objectives were in fact to be achieved. The plans often provide an ordering of critical dependencies, of what must be done by when if other things which follow from them are to be initiated, what must be done by when if the project is to achieve its delivery dates and so forth. The plans are effectively a collection of targets which the team members are called upon to *try* to meet. The targets are not precisely calculated to give the team members just the time it takes to get the job done, no more no less, for such targets are characteristically guesstimates, or, more often, are reiterations of the specifications of the project's initial design - these are the things that will have to be achieved if the project is to deliver a project which can meet its performance targets at an appropriate cost and by the delivery date. It is the project workers' task to solve these problems, to find ways of putting the project's technology together so that it will work, to keep costs down and to pace the work so that the interdependences can be facilitated and the final delivery dates desirable achieved.

The incumbency is not upon the planners to generate an optimised plan. They may not be able to do this, for there are many problems which cannot be resolved at the level of planning - there can, for example, be tensions between the cost and the quality of the product which are *present in the plan* and which are visibly so - the planners cannot, however, themselves provide through planning activities ways in which these tensions can be resolved - it is not their job, and the tensions are therefore *handed on* to the project - within the course of its work, those tensions can be confronted and some ways of resolving them *perhaps* found. Processes in organisations do not necessarily involve the stepwise solution of problems i.e. the solution of a known problem prior to the identification of other problems, but may, in fact, involve the passing on of problems 'down the line'.

One prominent example of this, from a study of avionics development, concerned the ways of organising the project which was through the strict allocation of 'person hours' to the project. Keeping the cost of the project low was a major priority, and so the allocation of 'person hours' was a very strict one, which was also designed to keep precise control over the work. A number of hours were allocated to a task, and could not be exceeded, or at least, could not be exceeded if this would add to the project's total hours. Hours could be 'borrowed' from one part of the project but would have to be repaid at some later time. Of course, the time allocated for the completion of tasks is not nicely calculated, for how long it will take to do particular tasks *in actual practice* is only something that can be guessed at, nor is the total for the project a nicely calculated figure with respect to how many hours the work involved will actually take. It is, rather, a figure set with respect to the requirements of getting the work and done while keeping the costs down, and the problem of finding out how to do the work within the hours available is one which is handed on to the workforce. In this case they, in fact, resolved the problem - because they saw their future employment at risk, they were prepared to work to deliver the project within the hours supplied primarily by subsidising it through work on their own time, putting in a great deal of overtime, working at weekends, putting in time which would not count against the official allowance of hours.

2.4. An ethnographic view of mechanisms of interaction

A mechanism of interaction is a device that stipulates and mediates the articulation of the distributed activities in organisations, projects, and the like. They are tools said to reduce the complexity of the articulation work. As tools and technologies for articulation work, we as ethnographers, seek to understand them in their full details, as they are seen by participants to the setting were they have their voice. As artifacts MOIs may be persistent and accessible independently of any particular situation, yet their meaning must arise from particular situations and we seek to give a description of some of the ways in which mechanisms of interaction acquired a sense or meaning from the roles they had in the organisation of activity we observed.

In the following section we consider the meanings MOIs acquired from their situated use and we view MOIs as a class of *usage* of symbolic artifacts. Consequently, we suggest that an artifact that is used as a MOIs may have more than one purpose, that it may be used in different articulation tasks and other non-articulation tasks in the primary field of work. In this way we can consider how one artifact may be used in different situations to support coordination as well as cooperation, for conveying information as well as for articulating cooperative working. An artifact, its features, its format, its functionality and so on, may of course be more or less suited to these usages to which it is put. Certain generic features of artifacts may make them more or less suitable for use in supporting articulation work, features such as visibility, flexibility and the like already discussed in Strand 3 work. An artifact may be well or poorly designed for articulation work. In this way an object may, for example, be well suited to supporting articulation work (like a project management tool) but might be poorly related to the field of work; and similarly an object in the field of work may be made to work *as* a MOI in the absence of other perhaps more suitable artifacts that could better afford articulation work.

Additionally, we shall orientate in reporting the field study to the relationships between artifacts and representations used in the domain, how they are brought together to do certain tasks, how they are linked and understood within the context of the organisation and the project as a whole. Lets us then try to illustrate some of the above statements with an example from the field.

3. Case Study - Photocopying and Printing Equipment

These preliminary things said we can now begin to turn our attention towards our first case study and the description of the work and mechanisms of interaction involved in designing and developing the hardware and software for photocopying and printing equipment as this is routinely undertaken. This study is one of an on-going series into such engineering projects (ref. Anderson et al ECSCW93)

The case reported here involved a project that was, when this field work was conducted, in the midst of testing a fleet of prototype machines and attempting to achieve the stabilisation of the mechanical and software configurations of these machines, such that the project could enter a next phase of testing.

3.1. Background: Progress by Problem Solving

3.1.1. Listing Problems

The work within the project was conducted as such, work which is contributory to the progress of the project and as such needed mechanisms by which individuals and teams could cooperate and coordinate their input. On the project the engineers had, at any moment in time, a set of tasks in hand, a set of things upon which they were (or should have been) working. Here we report on how the cooperative work on the project was organised by and conducted through a 'problem solving' procedure, which involved the identification and recording of problems, and the creation of problem lists. These list artifacts could be generated in various forms, in levels of detail and number of problems listed, and individuals could be allocated problems and with lists enumerating which problems were theirs. The engineers would, therefore, be in possession of a list of problems which were 'theirs', it being their task to solve these problems. The problems list had to be related to work load, and their objective was to be clearing their problems list.

3.1.2. Reading the Ratio

The size of the problems list relative to their work load was a variable one; at the time we were studying the project it was usual for engineers to have a large list of unsolved problems, far more than they could be working on at the time, and steadily accumulating additional problems, but this was seen as a 'cyclical' feature of the project, a natural, only-to-be-expected, nearly-normal-for-this-phase of the project matter. It was expected that, for a time, problems would be accumulating more rapidly than they could be cleared, but that this was because much of the work was going into finding the problems rather than into fixing them and, in any case, because the course of development of the design ensured that as its prototypes and early builds were run, lots of problems would be revealed, but, it was expected, that in due course, new problems would cease to appear, that the fixing of problems would continue and that the total problems list would begin to diminish. The judgment as to just how normal the development was not one which was precise, and so their was, on the large project, some vague anxiety that the ratio between problems arising and problems fixed should have been slightly more favourable than it was, but not so that anyone could say with great definiteness that there was a problem.

Thus, the individual engineer is provided with a list of problems to be solved, but the engineer is routinely expected to relate those problems to the project's problems, as we shall describe. It is a unremarkable but invariable feature of their work that the engineers attend to the work they are doing relative to how the project is going. They are required, that is, to take an interest in the project, and not merely in their own work. (This was not, of course, invariably true of individual participants; there were those who were alienated from the project they were assigned to, and would seek to make this manifest, and there was one individual who was notorious for his unwillingness to attend meetings of any descriptions, something which others were willing to indulge in the light of his reputation as an outstandingly skillful engineering draughtsman).

3.1.3. Producing Problems

As we have said, when this field work was conducted the project with which we are here concerned was in the midst of testing a fleet of prototype machines with tests aimed at highlighting problems in design and construction. The test operations involved a number of machines being run pretty continuously through the working day, at one stage even on Saturdays. The test operations involve the photocopier machines in being used to print and being operated under conditions which simulate ‘normal use’. The machines are operated by some (usually) casual employees, who are required to run printing jobs on the machine in accord with a ‘test matrix’ and subject to a set of rules.

Test Matrix

The test matrix specified the type of printing the employees were to perform with the prototype machines. They were required, that is, to operate the machines according to a sequence in which the kind of print job to be run, the size of paper to be used, the number of copies to be printed, and so forth, would be varied - thus also varying the amount of toner and paper trays used and so on. The details of each job were provided in a manual and the operator would work through a cycle of them, and then operate the cycle over again. This diversity of operations in the tester’s job matrix was to ensure that the machine was used under the diversity of conditions and for the range of tasks that a machine might ‘in real life’ be used - thus, the machine would be required to be run with transparencies and labels, for example, with different qualities of paper, and under different conditions of humidity and temperature which can critically effect performance.

Test Rules

The test rules are effectively designed to achieve a simulation of ‘normal use’ by constraining the activities of those who have worked for a long time and closely with machines under test, and preventing them from making use of their familiarity in dealing with any problems that the machine might present. The presumption is that ‘normal use’ is typically by persons (‘users’) who have no comparably sustained familiarity with the machines and their ways. In other words, the responses of the operators to malfunctions were rule governed, such that they were permitted to respond to certain faults by, for example, clearing a paper jam themselves and restarting the machine, but on other occasions they were required to call in the 'tech rep' - company repair staff who would come in and would correct the fault. The test operators' activities were, therefore, organised with respect to the users' lack of familiarity. The 'user' whom they were to simulate was someone with only a minimal knowledge of the machine, someone who had no more than a routine grasp upon its operations, and certainly not someone who had long standing, detailed and intricate familiarity with the particular machine's ways, and who could devise their own resolutions of faults those machines might manifest. The operating rules are developed to prevent them from taking advantage of their familiarity with the faults of the machines, from using their accumulated knowledge of what will get the machine operating again. The point of the test is not to find ad hoc ways of solving the machines problems, but for the project to find ways of reducing those (design) faults which will occasion the routine user to call a maintenance engineer and to that extent they want the test operators to simulate the conduct of those users who when they find they are unable to get the machine working again by means of the specified procedures will therefore be inclined to call for the engineer. Thus, the operators were required to follow the standard rules for clearing paper jams, because, of course, the machine provides specifications of the way in which paper jams can be fixed, but, if those corrective feature fail, then the test operators are prohibited from taking further measures, even though they might be able to fix the fault, in favour of calling in the tech rep.

The utility of such an organisation of the simulations was, of course, in respect of engineering problem solving in that interventions performed on the machine were rule governed and therefore known to those attempting to understand the problems with the machines, an activity we shall discuss in detail later.

Additionally we can say that in this case, 'the user' is a pragmatic, rather than an ideological construction. The 'user' is seen as someone who is assumed to be using the machine on the basis of cursory inspection, and who will undertake 'reasonable' courses of action (though they might, in other connections, be envisaged as people who would take 'unreasonable' courses of action). They are assumed to be people who, for example, will, upon having cleared a paper jam press the restart button, and who, if this results in failure to restart the machine, might press the 'reboot' button. These are conceived, from the engineer's point of view, as reasonable responses to the situation encountered, and as ones which must, therefore, be accommodated in the conception of the machine's ordinary operations.

Performance Levels

The performance of the machine during each day's testing was judged on a number of criteria. Firstly the malfunctions that occurred during printing operations and the measures taken to correct the faults were recorded by test operators by completing 'Fault Report Forms'. Likewise, if 'tech reps' were called out (in what was known as 'unscheduled maintenance' calls or 'UMs') they would record the nature of the fault they had found and the measures taken to correct it. The rate of

'UMs', per million sheets of paper printed, was a criteria of performance (with a target of no more than 6 UMs per million sheets). A second criteria was the length of time a machine was 'on-test', as opposed to 'off-test'. A machine was 'off-test' for the time taken for repair staff to arrive and diagnose a fault and provide a solution (termed 'investigations') or to modify or replace parts (termed 'fixes'). The aim is to have the machine 'on-test' for as much time as possible, with as few faults as possible and, furthermore, for it to meet a target of the number of pages fed through and printed. A number of other criteria (such as the number of sheets printed per print cartridge) were in operation but the point is that the ultimate project aim was to get the machine's performance up to a certain consistent level at which it can be operated without modification of parts or software.

3.1.4. Recording Problems

Reporting Faults

As mentioned, malfunctions with the prototypes during testing were recorded on a 'Fault Report Form' (FRF). FRFs are artifacts that contain extensive detail of the malfunction, involving a number of standardised categories of information (machine number, operator etc.) and space for (relatively) discursive descriptions of the malfunction. The FRF records the time at which the fault occurred, the number of sheets printed since the last fault, the number of faults recorded for this machine, the conditions of temperature and humidity under which it was operating, and the nature of the fault and of corrective action taken. The Fault Report Forms are numbered (e.g. 262, 263 etc.) and there are also standard fault codes (e.g. 4455, 6088 etc.).

TEST NAME	M/C No	FRF No.	ACTION LETTER		DATE RAISED	ZONE
THAMES B1-4	**Y005**					

ELECTRICAL SUPPLY				CASS COUNTER		CASS IDENTIFICATION		CASS VOL	S/W No	ESS S/W	HUM	TEM
115V 60Hz	LVN	LVL	LVH	START	FINISH	START OF CALL	END OF CALL					

PAPER		CALL INIT TIME		JOB No	IMAGE	SIMPLEX/ DUPLEX	PAPER TRAY SELECTED HCF/TRAY2/TRAY3/TRAY4
SIZE		CALL START TIME		JOB MODE: STACKER/OCT/OFFSET/NON-OFFSET		START MTR	
WEIGHT		CALL FINISH TIME		TYPE OF CALL: UM/IM/INFO/IPM/RETRO INST/EI/ADMIN/WAIVER/CCA		FINISH MTR	
CODE		LOST TIME		STATUS CODES:			

REASON FOR CALL ORIGINATOR:
SERVICE ACTIONS
SHORT TECHNICAL SUMMARY (Max 44 characters)
USED PARTS: (Numbers and Description)

ENGINEER		DATE COMPLETED		SUBSYSTEM ALLOCATION	

SUBSYSTEM RESPONSE	CR No

PDT NUMBER	DEPT.	REALLOC.	VOL. TYPE	FEP	FLAG	COPY TO

ENGINEERS MUST COMPLETE FRF's ON THE DAY THEY ARE RAISED

A ‘Fault Report Form’ (redrawn)

Reporting Daily

The ‘Daily Report’ is a structured paper artifact that is read out in the course of a ‘Sunrise Meeting’ for which it is the main focus of business. The routine use of the document is to organise and to generate talk in these Sunrise Meetings which in turn are intended to progress the project work, as we shall see. The Daily Report is a summary of the FRFs and a collection of separate sheets, each one of which records the test performance of one of the fleet of prototype photocopy machines. These summaries of the FRFs contain the Fault Report Form number listed alongside a (typically) abbreviated statement of the fault. The collation and summarisation of the FRFs is part of the specialised job of handling the project’s data analysis and done by the project’s data analyst. As mentioned earlier, the project is concerned with performance levels and, consequently, for each machine a cumulative record and display is kept of the number of sheets fed through the machine the number of UMs, the time ‘on test’, the number of days in a particular test chamber with specific humidity and temperature conditions, and so on.

3.1.5. Project Structure

Before we consider these artifacts and their usage in this project, let us say a little about the overall project structure as this directly contributed to the meaning of some of the devices used in the work.

The organisation of the design team was, of course, one of people with specialised skills who were allocated to specialist tasks within the design and development process. In this large project the team was subdivided into groupings known as ‘modules’ . Importantly these module groupings corresponded to the composition of the machine being developed - thus there were sub-groups concerned with ‘the stacker’, ‘the fuser’, ‘processes’, ‘software’ and the like. In this way the various functional modules of the machine are associated with sub-groups of the project team, such that entries such as ‘paper hand’, ‘software’, ‘print cart’, and so on, indicate *both* a part of the machine *and* a work group. Consequently, a part of the machine which is alleged to be the subject/source of a fault is also the work group which is responsible for handling the associated problems. The allocation of a problem to a subsystem means that it is the responsibility of the work group representing that subsystem and therefore the allocation of faults is also the distribution of further work tasks.

This said, however, the projects’ sub-groups still worked together in many senses and we shall consider the details of one of the many project meetings in which the engineers would be present to each others work, if not actively involved in considering it.

3.2. An Occasion of Use: The Sunrise Meeting

The ‘Sunrise Meeting’ was an occasion in which the problem lists, the FRFs, the Daily Reports, the Project Structure, and so on, came together in an attempt to progress and monitor the project. In this meeting the production and recording of problems was linked, in particular ways, to the organisation allocation and articulation of the further work to be completed on the project. Below we examine the mechanisms through which aspects of project organisation interact, and how the daily Sunrise Meeting was an occasion which was specifically organised to bring things together, both members of the team and issues in the development of the project.

The Sunrise Meeting in this case consisted of key members of the project team, with representatives of each module group within the project. The meetings started at 8.30am, lasting for one hour and occurred each morning of the working week. As we have said the project had entered a testing phase and it was the business of the 'Sunrise Meeting' , at the time we were recording its affairs, to be dealing with test operations, these being mediated through the 'fault report forms' being generated by those who were carrying out the test operations. One of the primary tasks of the sunrise meeting was, therefore, to deal on a day to day basis with the faults reported in test. The participants in the sunrise meeting were distributed with print outs which summarise the number of fault report forms for each machine and the general nature and provisional module allocation of the fault reported. The project's data analyst (and the test operations manager) are in possession of full copies of the FRFs and it is the data analyst who plays a central role in the meeting by reading through the full fault report forms.

The meeting reviewed the contents of the 'Daily Report' by considering the fault reports for each machine in turn, the order of review being governed by the alphabetical sequence of machine numbers: thus, machine A007 is taken first, machine B009 next. The organisation of the meeting as a progression through these forms on a machine-by-machine basis resulted from a concern to track the history of the specific machines, despite the varying composition of the test fleet, because the fact that it is a specific machine which is behaving in a certain way may be something that matters. The machines are considered in order of their age, those from the earlier build first, and so on, and the machines are known by a letter (for the build) and a number (their number in that build). Then the fault report forms are read through one by one, with the details of the faults being reported and of the measures given to deal with them.

Thus, the data analyst reads out the machine number, the FRF number (e.g. 262, 263) and the repairers' statement of the description of the fault. (The data analyst also brings along the original fault report forms and, occasionally, materials that accompany the report. Thus, if the fault involves unevenness in the distribution of toner on the paper, errors in text printing, staining of paper or the breakage of some small piece of hardware (such as a screw) then a sample sheet of paper or the broken pieces of metal will be attached to the original FRF. There is, then, a reading out of the (typically) more discursive description of the fault and the circumstances of its occurrence and the sample may be handed over for close inspection by one or more participants).

3.2.1. Using Representations Together

We can see how the representations used in the project and described earlier are brought together in the Sunrise Meeting. Firstly, each of the 'modules' were expected to be represented by their respective leaders, or in their absence, by someone deputised by them. This requirement that someone from each module be present, allowed the sunrise meeting to be organised around the representation of the various 'modules' into which the project team is subdivided. As we have described these 'modules' were characteristically identified by the name of the part or function of the machine under development for whose design the module teams are specifically responsible, such as the 'stacker', and 'fuser' groups (along with 'software' and the 'systems' group which were responsible for the integration of the machine as a whole, and with the manager of the 'test' operations through which the early builds of the machine were now being passed).

Secondly, and following on from the module organisation, the 'management by problem solving' procedure was able to operate, in part, through the allocation of 'problems' to modules. Part of the business of the 'Sunrise Meeting' was to confirm provisional allocations of problems to modules, and attendance of someone from each of the sub-groups was therefore to ensure that someone was present to speak on behalf of the module and to the problems which might potentially be allocated to it.

Thirdly, the FRFs and Daily Reports mediated the results of the activities of the test operations in producing and recording problems for the Sunrise Meeting.

However the mechanism was not simply a one-to-one allocation of problems identified in the FRFs to tasks for project sub-groups/machine modules. More was involved in the Sunrise Meetings and more was made of the FRFs, the Daily Reports and the like, as we shall consider. Let us first, however, say a little more about the project's progress as a whole.

3.2.2. Keeping to Schedule

The project meetings routinely *began* with displays of or discussions about project progress. These involved, particularly, the display of an artifact - the project schedule. The project schedules were displayed in order to show how work was going relative to the targets that the schedule had set for it, and, of course, to look for potential signs of slippage from them.

There were various measures of performance and progress such as the ratio between problems found and problems fixed and we have described how this measure was to be interpreted as a feature of the stage the project was at, such that even a high ratio could be 'only-to-be-expected' and 'nearly-normal-for-this-phase of the project '.

At the time we were recording the Sunrise Meetings the project was having difficulties in moving toward its targets (with a graphical display of the diverging lines between the target performance and actual achievement being permanently on display on the wall of the sunrise meeting room). There was, at that stage, no doubt but that they would get to those targets, or close to them, but there was a concern about whether they could attain them quickly enough. The project was, in various ways, falling behind, and so it was an omnirelevant concern as to how any day's performance related to overall performance, and as to what any particular problem might mean with respect to progress. Consequently, the summary data about current performance against targets which was provided, and which showed the current rate of unscheduled maintenances, the time 'off-test', the total sheets run through, and the like, was one of the first things to be checked about the machines. (How much time the prototypes had spent in operation the previous day and how many sheets had been fed through them was important from the point of view of getting significant rates for faults).

3.2.3. Reading the Problems

We have seen how the test matrix was intended to get the *machines* to exhibit their faults, and that they did and that they would need to be fixed. However the concern of the team was with the prospect of, and the need to fix, design faults. The test operations were designed to get the *design* to exhibit its bugs. Furthermore, the machines were run in order to see if there were any faults in the design which would threaten to prevent the machine from reaching its target. The faults, reported in the FRFs were of different sorts associated, with malfunctions in different areas of the machines construction and design. However, the faults were also of different sorts in terms of their significance and meanings for the project., its progress and ultimately its success or failure.

In the Sunrise Meetings the fault report forms were to be taken one by one, and each fault considered individually, but the progression through the forms, and the progression through the succession of Sunrise Meetings was something to be considered from the point of view of the meaning of the faults for the progress of the project: at what rate were faults occurring, and was there any pattern to any of them, were they the sorts of faults that they should now be encountering at this stage in their testing work or ones they thought they had seen the back of, what kind of time scale might there be to a fault, and could its fixing delay other things, was this fault one they had not seen before, or merely a variant of a fault that was familiar and which was already in hand.

The kinds of problems with which they are confronted are such as this:

- that testers follow out the standard procedure in response to a fault signal - an 'eleven oh nine' - and reset the machine, but were met with another fault signal,
- that the interfaces of the two parts of the system (the IOT and the ESS) give different fault messages (with the IOT system and the ESS system being the parts of the system which, respectively, manage the electro-mechanical business of printing - the imagining output terminal - and that which is effectively the printing job manager - a complex software system which specifies the image)

- in the face of such problems, the software is reloaded but this does not resolve the problems… and so on

In other words they would encounter many problems where there is a discrepancy between the fault occurring and the interface display which identifies the fault, there is a discrepancy between the faults displayed on the different interfaces of the machine, the corrective measures either don't correct the fault or don't generate the appropriate interface display,, and the like - and sometimes they would encounter these as a long, long catalogue of individual faults which would be examined individually with respect to their individual solution.

Categorising Problems - Looking for the Critical

The problems were categorised in order of seriousness. For example, routine faults are those that can be expected as a matter of course even in the final version of the equipment and which will be standardly corrected by users or by calling in company maintenance staff. Other faults exhibited in testing require readjustment of the design of some mechanical part of software feature - a metal bar may be repeatedly breaking, the photocopier software may display a fault code when there is no fault, and so on. The Sunrise Meeting read the FRFs with a view to interpreting which reported faults indicated problems that were 'critical' (i.e. which threatened the project's life), which were 'major' (which could impact in a significant way upon the QCD's - Quality, Cost and Delivery considerations), and the 'Ordinary' problems (the ones which could be solved straightforwardly enough given time and effort). One of the projects artifacts was a display of the problem totals and the distribution of project problems: how many, if any, critical problems did it have, how many major, and how many ordinary. The display was a 'state of project' display.

3.2.4. Recognising Patterns

As we have noted the meeting, as well as reading the FRFs for critical problems and to interpret the reports in terms of fault classifications as a basis for problem solving and decision making, also had to use the FRF and Daily Report mechanisms to identify patterns to the problems, their origins and distributions. For example, the types of problems described above - of interface discrepancies and the like - where, from the point of view of those involved, familiar ones which are typically allocated to 'software' and the project knew that it had a lot of problems with the fault codes.

In this way the FRF was read to determine, among other things, whether the reported fault was one the project had seen before, whether it was merely a variant of a fault that was familiar and whose investigation and solution was already in hand, or whether it represented something new. Consequently, the Sunrise Meeting had to first establish whether a fault fell in the category of 'problems we know about and are working on' (for some of which there were candidate solutions not yet been implemented, while others had as yet no current solutions). The meeting then had to decide which of those were 'faults we had not seen before' but which meant nothing, and those which might present a real problem. For example, on one occasion one participant was concerned to have people recognise the ‘exceptional’ character of a fault. A part of the laser scanner had failed, but this was not the significant fact. The significant fact was that the part had catastrophically failed. The normal failure pattern is a stepwise one, in which there are discontinuous falloffs in performance, but in this instance the transition had been abruptly between full performance and complete failure.

3.2.5. Reading the Reporting

In the discussion section below we consider in more detail how the reporting done by testers and ‘tech reps’ is orientated to the reading tasks of the Sunrise meeting. However we can say here that on occasions the Sunrise Meeting critically read the reporting, done via the FRFs, to determine:

(a) whether there was enough ‘relevant’ detail (to decide whether the fault is a familiar one or otherwise) and

(b) whether such things as the sequence of relevant machine behaviours, the sequence of operator actions or the correspondence between the sequence of operator actions and machine behaviours, and so on could be worked out from the way in which the report had been written.

For a (hopefully) clarifying example, there is the case of an FRF which reports that the ‘pause button’ on a machine had been illuminated and where the inadequacy of the report was that it could not been determined whether the operator had pressed the ‘pause button’, thus causing it to go on or whether the pause button had illuminated without being pressed.

The ‘adequacy’ of the detail is also determined relative to the requirement of replication. Often the most that can be determined from the discussion of the FRF is that there is the possibility of a problem. Whether or not there is a problem is for them a question of whether a particular fault can be reproduced, whether a particular concatenation of circumstances will invariably, or which unacceptably high frequency, give rise to one or more faults. Thus, another part of the ‘adequacy’ standards for reporting is the extent to which detail is sufficient and of the right kind to offer a prospect of reproducing the fault.

3.2.6. Changing the testing

We have described the trail from testing activities to task allocation on the basis of problems identified, FRFs mechanisms and their interpretations in the Sunrise Meeting, however among the other issues discussed at the Sunrise Meetings were concerns about the rules and polices that guided the testing activities themselves.

The project we observed was tightly resourced, and there were issues which were occasionally raised in the Sunrise Meetings about the availability of test machines. There were those who wanted to have access to the ‘early build’ machines for their own specific purposes and which could not be integrated into the interruption of test operations for engineering investigations. There were problems, too, in supplying machines for the important, and major, part of the software writing operation which, unlike the rest of the project, was not based in the UK but in the US. So, one of the roles of the Sunrise was to discuss priorities and rules of test procedure, how to share out the machines becoming available amongst those who wanted some or greater access to them.

As one example we note the debates over the use of ‘waivers’ in the test procedure. These discussions arose from the project’s desire to exit its present testing phase (what was known as the ‘score’ testing phase), when a good deal of reworking of the machine was taking place, and to enter the next scheduled phase. However to do this required that the configuration of the machines in test be more or less frozen, so there were discussions as to the rules under which the testing was done, whether they should try to set limits on further changes and whether they should lift some of the ‘waivers’. The waivers were a ‘device’ imposed to enable the project to reduce the number of problems it was handling at a given time, a matter of managing work load. The waivers covered problems which they knew they had but about which they could not do or were not going to do anything about at the present time. Whether those waivers which were currently in operation should or should not be lifted were matters for collective deliberation and decision, and the point was to get the meeting’s agreement to such decisions. The question typically was, of course, whether these decisions were timely enough, whether there was a pressing need to take steps, such as lifting waivers, which would move them toward the targets they needed to meet to exit the score testing phase, or whether such a move would be premature, and perhaps even time wasting, insofar as they would lift the waivers only to find that they then reveal such a plethora of faults that they simply have to put the waivers all back on again. There was a further recognition, though, that the waivers were possibly giving a false impression with respect to the progress they were making in testing. In other words, the fact that they were doing nothing about certain problems offered the possibility that they were concealing the existence of serious problems, that when they came to look into these problems they would find they were altogether more problematic than they were expected to be, or that they were in fact obscuring other, and serious, problems.

Consequently, while the main business of the Sunrise Meeting was to review the Fault Report Forms, which were being generated from the test operations, the meeting would also deal with problems in the organisation of the activities of testing itself and the making of decisions about test rules and policies.

3.2.7. Finishing on time

COMIC-Del-3-1 has noted that ..

> “Mechanisms of interaction are always managed under the constraints of the policies dictated by the organizational context” (page 14)

.. and we observed in this case, what we call, an ‘organisational inflection’ towards ‘quality procedures’. We have reported how the project concerned itself with performance criteria and allocated responsibility for faults and problems to specific project sub-groups, who were often those who originally designed the relevant aspects of the prototype. Indeed the testing described above was known as 'score' testing, in that the faults which were being revealed in testing were being scored against the modules to which the faults were allocated. However this 'organisational inflection 'also influenced the running and practical management of the Sunrise Meeting itself - perhaps because one aspect of these 'quality procedures' was a reasonably strict compliance with scheduling. Consequently the meeting was expected to begin near-enough 'on time', which meant in practice some three or four minutes after 8.30 at the latest for the Sunrise, and to finish on time, not least as a courtesy to people who were gathering outside for the next meeting. By 8.34 there were usually enough people to render the meeting quorate, and a serious attempt was made to get the business done within the hour. The meetings would exceptionally run over time if there was a difficult issue, perhaps by ten minutes or so, but, unless there was a policy problem, then the aim was to get through the fault report review by the 9.30 deadline, and this was characteristically achieved, though there might have to be a hurried conclusion to some meetings, with bits of business being finished off as other people leave.

Consequently, the mechanisms, artifacts and their practical management in this meeting had to afford the meeting finishing on time, to schedule, in accordance with the organisational inflection and the policies of quality procedures.

4. Discussion: A Social Distribution of Knowledge

As we have said the organisation of the design team is of people with specialised skills who are allocated to specialist tasks within the design and development process, and one of the first things we need to do is to say something about the ways in which that fact matters within the design process and for mechanisms of interaction used within such projects.

A notion which we shall apply in this discussion is that of Schutz's concept of a 'social distribution of knowledge', and his treatment of this as what we will term 'an oriented to' feature of social life. There is much talk about demonstrating the 'socially organised' character of knowledge, and this involves, in the contemporary Sociology of Scientific Knowledge, the attempt to establish what are perceived to be controversial and counter-intuitive claims. It is, however, the clear import of Schutz's work that the fact that knowledge is 'socially organised' is something which is *known to us*, which is a matter of 'common sense'. Knowledge is unevenly distributed, but in orderly ways. Schutz tries to exhibit this point via a typology which relates the stranger, at one extreme, to the expert at the other, with 'the man in the street' and 'the well informed citizen' as intermediary types. In this way he seeks to emphasise that:

(a) knowledge is unevenly distributed,

(b) that the unevenness is structured in socially ordered ways and not randomly and

(c) that both (a) and (b) are experientially known facts of social life for all we members of a society, organisation or project.

Thus, the conduct of our everyday affairs (and the mechanisms deployed in stipulating and mediating these affairs) is oriented to the fact that there is the possibility of an uneven distribution of knowledge amongst us, and that this uneven distribution is one that, in the course of our relationships , we may have to manage.

There is one other abstract point from Schutz which may be of some use in approaching these issues, which is the fact that the distribution of knowledge within a society, organisation or project involves the *interplay* of:

(i) the extent to which things are known in common and

(ii) the extent to which there is an uneven distribution of knowledge.

Central to Schutz's conception is the notion of 'common sense knowledge', the degree to which things are known in common, and the extent to which social life is conducted *on the assumption* that we need make no allowance for differences in knowledge between those whom we are dealing with and ourselves (though of course such an assumption can be fallible). Additionally, however, there are times when such assumptions do not apply, but these occasions are of interest to us too in that suspending the assumption of common knowledge is itself a socially organised matter. For example, we go to the physician in the expectation/ hope that the red spots visible on the surface of the skin will be recognisable to the physician as manifestations of some illness syndrome in a way that they are not to us, that where we see 'red spots' the physician may seek 'chicken pox' or something comparable. Thus, the notion of the social organisation of knowledge is something which can be used in the analysis of expertise on the design and development team, the activity of the 'Sunrise Meeting', the MOIs upon which it is focused and their reading. For example, faults are reported to the Sunrise Meeting by the testers in the belief that the module leaders present at the meeting will make sense of them, will recognise their nature and read into them their significance for the project perhaps in a way that the testers could not. Additionally, the members of the Sunrise Meeting are attentive to the interplay of common knowledge with distributed expertise that is at work in the meeting, and about which we shall discuss shortly. Firstly, however, let us say a little more about the assembly of teams on these projects and their make up with members with different expertises.

4.1. Designing the Team

The design and development team is often constructed around the uneven distribution of knowledge, its members will have particular professional expertises, and, in addition, they will have a variable depth of experience within their expertise. The distribution of knowledge within the cooperative ensemble of the project is calculated with respect to its functional efficiency; the construction of the team is oriented toward having available the variety of expertise - in this case it is electrical and mechanical engineering, xerographic, software etc. - which will be required for the effective development of the product, and will have these in sufficient depth; the project team is characteristically a mix of levels of experience, it being the case that they do not want to overload a given team with all the most experienced engineers, and that for much of the work, relatively limited experience will do, though of course there is also the concern that there be some people with depth of experience in the area, where they have some acquaintance with photocopier engineering and, indeed, preferably, with the very machine upon which the work is being done, or one very close in design to it. Designing the composition of the team within the development organisation is, however, subject to constraints such as:

(1) the extent to which there is anyone available with experience of the work that is being undertaken. (For example, cases where when you are shifting from developing photocopiers to developing printers, you have people with a lot of experience of photocopiers, but none of printers),

(2) where people with the desired skills are in short supply, and where the project does not have the competitive edge to command the scarce skills. (For example, cases where a 'mickey mouse' project needs to attract software engineers with rich photocopier experience),

(3) where the experience structure of the organisation is unbalanced. (For example, where, as in our case, due to restructuring, the organisation is top heavy with long experienced and senior engineers, and relatively short on junior ones),

(4) where the small size of the team can affect the range of skills available to it, and where the capacity to do the work will have to be found from amongst the team members, with people having to do work for which they are not best equipped.

That the team is a composite of persons with diverse skills, and other concerns, is, of course, something to which the members of the team are sensitive and attentive. That there are different points of view amongst them, and that there are different interests is something which they are well aware of, just as they are aware of the risk that these discrepancies can give rise to troubles on the project.

Certainly it was the case that these groups acknowledged their differences in the ways they spoke of and to each other. Thus, they would speak of 'electroids' and 'mechanoids', terms of a somewhat disparaging nature, which referred, in these cases, to those in electrical engineering as against those in mechanical engineering. However, these engineers were ones who had been working together in the same organisation for a long time, and were very well known to each other personally; they would meet each other in different project and organisational contexts in the course of a week, would run into each other in the corridor and dining room, and shared, of course, a history of working on previous projects, some of which involved them in working abroad for some months at a time together, experiences which would result in the telling of stories which had the 'together in a foreign country' character. The derogatory remarks were typically, therefore, cast in the terms of a friendly opposition, and the terms would, indeed, be self applied in the sense of 'remember, I'm only an electroid, so I'm not supposed to know about/ understand/ be interested in this kind of stuff' or of the 'If you'll forgive the intervention of a humble electroid'.

The working together over a long period gave these parties, too, an awareness of the competence, reliability, and character of each other. The experience was, in their respective judgments, a proven experience, and there was no problem within the teams we studied of the team having to 'carry' senior engineers who weren't up to their job. The members of the teams we looked at were reciprocally inclined to see that the others they were working with, that they knew about, were quite capable of dealing with the work that was required, and of making up for deficiencies in their knowledge. For example, due to restructuring a large proportion of the staff of a large project had departed, either for retirement or for other sites, which meant that many of the senior engineers on the project had taken over at a late stage in the project's development, so that they were distinctly lacking in experience with respect to the specific project and its detailed history. It is often a considerable advantage to know much about the specific history of the project, the decisions that were made in setting up the design and implementing it, but this simply was not available to these engineers; it was a deficiency, and one which could cause them inconvenience, and certainly leave them working with a design they would rather not have, but which did not cause any anxiety as to their respect to get the work done without it.

(We shall not discuss this here but the competence of managers was not so equably judged as was that of engineers, and the difference in the ways in which managers managed were very prominent in judgments about what kind of problems could engineers realistically expect them to solve, what kind of problems were they going to create, and how far could managers be depended upon for backup in dealing with project issues).

We have commented in the introduction about the use of mechanisms of interaction in coordinating *between* different projects and as acting as inputs to the managing of staffing constraints within a development organisation where skills have to be allocated *across* projects. However, *within* a project such as the one we are describing here, arranging and orientating to the mix of skills displayed by project members was very much a part of project and organisational life and the cooperative working it involved. In this case the activities of the Sunrise Meeting particularly showed the social distribution of knowledge at work.

4.2. 'Engineering Mentality'

Despite the distribution of specialist knowledge across the project, its problems were not, in project meetings such as the Sunrise Meeting, primarily treated as proprietary matters, but as, rather, project problems. As we have described the Sunrise Meetings commonly began with discussion not of specific problems but rather the total relative to the project's schedules. For the project as a whole outstanding and unsolved problems were bad news, particularly when reviews approached and ultimately, at a certain stage in its progression, that the project should have any problems would be a source of worry. Therefore, the meeting as a whole was concerned with if there were critical problems, how many and how bad were they and how realistic were the chances of resolving them, and how soon, and how good or bad did it make the project look to have so many or so few problems. The ordinary problems were not, themselves, of particular significance in such contexts.

Consequently, the project's problems with the QCD's were not discussed in a proprietary way, i.e. solely by those with a specialist interest in them or to whom they had been specifically allocated. The discussion was 'project wide' in that anyone could contribute to their discussion and could make proposals with respect to their solution. In addition, there was the 'be there anyway' requirement, which was that attendance at meetings regardless of specific specialist involvement was a common requirement, regardless of whether one had a specific or immediate interest, one was called upon to show an interest in other people's problems as 'the project's problems', as we shall discuss below. Participation in the 'sunrise' meetings could be problematic from that point of view, for some participants, who were required to attend these meetings on a daily basis even though the topics the meeting was addressing was 'no business' of theirs, that the problems arising where overwhelmingly 'software' and that, thus, those from 'stacker' or 'fuser' might sit through a meeting in which not a single one of the problems raised bore upon their speciality.

Obviously, there was deference to speciality. and to the uneven distribution of knowledge. That someone was a specialist was something which was known, and the nature of their specialism would often be known to others. The part that people would play in discussion was of course related to their speciality, but the fact that others would speak to issues within their specialism was not typically treated as any transgression. It is also worth adding that one of the procedures which governed the conduct of meetings within the organisation, and which was routinely, but not invariably respected, was one which called for constructive contributions; criticism was supposed to be precluded from the discussions.

The pursuit of 'specialism' was not commonly problematic in respect of technical understanding. Much of this was common, at least to the extent that the specifics of a specialism were intelligible to others, were recognised to have their own legitimacy and , indeed, such specialist competence was heavily depended upon, with respect to the taking of advice and the practical management of problem solving. Persons could, indeed, focus upon their own preoccupations to the extent that the could rely on others to be taking care of business. Thus, the relation between specialism was commonly subordinated to the business of problem solving, a matter more of bringing expertise to bear upon the problem (as represented in and interpreted from the FRFs) rather than for contending between rival competences.

Though these were specialist engineers, they were also photocopier engineers. The engineers did look at things from their 'specialist' point of view but it was something to which sensitivity was displayed with respect to the diversity of specialisms. The project team was subdivided into groupings or 'modules' but these were groupings that worked together. Indeed, the project involved participation in many meetings in which the engineers would be present to each others work, if not actively involved in considering it, and the effect was that, over a period of time, people would acquire considerable knowledge of the photocopier as such, and of the characteristic problems and issues of these machines and of their development; their specialism was the focus of a diffuse, but often deep and detailed knowledge, of many aspects of photocopier design and operation, as well as of the exigencies and troubles of organising photocopier design and development teams. They were not, therefore, aware only of the aspects of the design or of the project's course which bore upon their specific competence, but were aware of the ways in which their work would impact upon others, of the general character of the problems that others faced, of the troubles they would have in dealing with them and so forth. Much problem solving was, furthermore, done interactively (between modules), involving specialists in the resolving of issues which affected more than one of them, differentially, perhaps, but consequentially, in the course of which they would, of course, have to explain what their respective requirements for a solution were.

One further consideration is that whilst they were 'fuser group' or 'software' they were frequently required to subordinate that identity to that of 'fuser group on the Thames project' or 'electroid on Centaur', giving priority to project problems over their particular task in hand

We see then a need to avoid painting a picture of the 'engineering mentality' which is necessarily inflexible and rigidly driven by procedures or constrained by mechanisms of interaction. This is one which tends to develop at least implicitly in much of the literature, with the Bucciarelli type of account assigning engineers to 'different worlds', (Bucciarelli 1988) which are, because of their background and expertise, discrepant with one another, and within which they are, to some extent, imprisoned without a capacity to grasp that there are other viewpoints. The writings of Alfred Schutz suggest an alternative to this 'speciality bound' view and an alternative that for us corresponds with our observations of the activities of the Sunrise Meeting.

4.3. Being There

We have noted how attendance at the Sunrise Meetings was required, that each module sent its leader or a deputy. However this attendance was not required merely on specifically functional grounds. Attendance was also seen as an element in the wider organisation of the project, as involving:

(a) the organisation of knowledge on the project and

(b) the exhibition of a collective orientation to the project.

Sharing Knowledge

The requirement of attendance at the Sunrise Meeting was one which involved the sharing of knowledge from the project. The matters discussed in the sunrise meeting had a ‘public’ character and, as we have said, anyone could speak to the problems or issues that were raised, regardless of specialism. Which is not, of course, to say that specialism was disregarded, for the capacity in which people spoke might well be seen to depend upon their speciality (the software representative might be seen to be responding defensively, for example, because of the extent to which the software was causing everyone trouble, and the representative of the ‘process’ module i.e. those concerned with the processes involved in image transfer, would be offered first opportunity to say what a pattern of misprints might mean with respect of machine faults). However, the requirement was for the members present to take an interest in each others modules and their problems, and to be aware - albeit diffusely - of other people’s work and what was involved in it. The business of being a photocopier engineer is not a matter of being knowledgeable only, and specifically, about the aspects of photocopying engineering in which one is specialised because, of course, the technical problems are ones which interact, and so competence in such engineering presupposes a general knowledge of the ways in which photocopiers work and of the problems that teams developing such machines encounter.

Showing Involvement

The Sunrise Meeting was intended not only to bring together artifacts, mechanisms of interaction, distributed knowledge and issues but also team members. In this way, attendance at the meeting was required with respect to showing that one’s involvement was with the project, and not just with one’s own job within it. This was a source of a mild tension, for the attendance at the meeting would be examined by at least some of the participants from the relevance of it to their specialist point of view. At the time which we were recording the meetings, there was, as already suggested, a very large number of ‘software’ problems involved in testing, and these were taking up a substantial part of the Sunrise Meetings, and some others would complain about the necessity for attendance - they currently had no business at the meeting, i.e. their parts of the machines were not giving problems and they were not interested in software’s problems, and they had other work they could be doing, rather than sitting around in the meeting, but their protestations were overridden by project management - they were required to attend the Sunrise Meetings in order to show an affiliation with the other people on the project. Attendance at the meeting was a display of orientation to the project as a whole.

Thus, with respect to the Sunrise Meeting, the participants were certainly oriented to their specialism in that they could look upon items of business to see whether they had any relevance to and any interest for them, and they were also attentive to their specialist positions vis-a-vis the business of the meeting, as to whether they were responsible for some matter or whether they might feel that 'they' i.e. their module was getting the blame for some error or failing, but these matters were required to be subordinated to the needs of 'the project as a whole' and their participation within the meeting was not necessarily to be confined within their specific responsibility.

4.4. Entitled to Read the MOI

As we have described the Sunrise Meeting concerned itself mainly with reading the FRFs and the Daily Report for a number of meanings and as basis for problem solving and decision making. In particular we have said how the testing resulted in faults of different sorts with different meanings for the project; how the meeting was concerned to distinguish from the FRF information between known and repeated problems that are worked on and those that had not been seen before and were possibly significant; and, finally, how the meeting occasionally considered the reporting in terms of the adequacy of detail provided by it. It is necessary, however, to emphasise a basic, but important and readily disregarded consideration. Namely, that the business of reading is itself socially organised and that it involves socially distributed entitlements.

It is not the case that anyone can take up a FRF, a Daily Report (or any other of the project's documents and MOIs) and be legitimately entitled to the expectation that they can make sense of its contents. There is, further, even a difference between the extent to which someone could feel entitled to understand what a document means in some *generalised* way, by virtue of things 'such documents' say, and that same person's capacity to say just what the document *specifically* reported in all important respects without being privy to particular matters about which the document speaks. The entitlement to understand the 'Daily Report' is available to those who have a familiarity with the working and reporting practices of the Development and Manufacturing organisation within which the project is being conducted, who have a familiarity with the specifics of the project that the Report belongs to, and that have a continuing involvement with the developing sequence of meetings within which the Report figures, but the capacity to fill out any particular feature of the form may fall to only one of the meeting's participants, viz, the one (say) who was there when it happened or (alternatively) who talked to someone who was there etc.

4.5. Reporting for the Meeting

We can again see an interplay of the extent to which things are known in common and the extent to which there is an uneven distribution of knowledge in the reading practices of the FRFs. We may see this in the way that the talk sometimes, though rarely, provides critical scrutiny of the FRF.

It is a presumption of the affairs of the meeting that there is a substantial commonalty of understanding between the writers (the testers and the 'tech reps') and the readers (module representatives) of FRF's as to how many of the faults are to be understood and how their description is to be detailed. It is, of course, part of the purpose of discussing the FRF's to enable the Sunrise participants to determine things about the faults that the tester's would not or could not notice, and particularly for these participants to draw conclusions about the faults on the basis of talking over the FRF's.

It is, however, expected that t he tester's will accumulate a familiarity with the pattern of machine behaviour and the practice of report writing such that (for example) their discursive characterisations will manifest the kind of fault that it is. A routine meeting occurrence is 'recognition of the same fault again'. Thus, the report will be examined as compiled out of a sensitivity toward 'relevant circumstances' as their sense would be understood relative to the recognisability of a fault as a recurrent one. Thus, the written up details of an FRF should display just those circumstances that manifest the status of problems as 'familiar ones' which exhibit a standard constellation of detail. Particular configurations of machine events and operator actions are involved in fault occurrences and those which match some features of a known configuration are not (necessarily) instances of the same fault. The tester is called upon to notice and report any untoward features which may accompany a given fault, and to have an appropriate sense of how much detail is enough for the meeting's purposes.

Thus, as we have noted the skeptical scrutiny of FRF reports is typically addressed to (a) the possibility of a paucity of 'relevant' detail sufficient to determine whether the fault is a familiar one or otherwise and (b) the incapacity to determine from the manner in which the details are formulated such things as one or more of (say) the sequence of relevant machine behaviours , the sequence of operator actions or the correspondence between the sequence of operator actions and machine behaviours. We described the case of an FRF which reported that the 'pause button' on a machine had been illuminated but that it could not been determined whether the operator had pressed the 'pause button' or whether it had illuminated without being pressed. We noted how the 'adequacy' of the detail related to the requirement of problem replication.

5. Conclusion

Mechanisms of Interaction are in many ways central to COMIC work since they are important interfacing elements between an organisation's computing systems and the work that these support. Strand 3 is particularly focused upon these, but they are also prominent in the considerations of other strands. In this paper we have been concerned to analyse particular mechanisms of interaction which articulate the work of many different groups within the complexities of a reasonably large engineering project.

5.1. Motivating a study of MOIs

We have emphasised the increasing perceived importance to modern organisations of speed, flexibility and responsiveness, which may be achieved through enhanced arrangements of coordination. The capacity of computer based artifacts to provide this enhancement is apparent, sometimes perhaps building on the kinds of artifacts which have long been in use in social life.

There are many different ways of viewing the organisation of work, and we have elected to approach it in this paper from an 'artifact based' point of view. This is an outgrowth of the central concerns of the COMIC project. We give attention to artifacts that support work since a significant part of COMIC's objective is to develop understanding of the way the introduction of such artifacts into cooperative work affects and contributes to that work.

The analysis of the Fault Report Form has been focused upon the way in which an artifact supports the day to day decision making within a project team enabling the provision of solutions to the 'what?' ,'how?' and 'when' questions which are perennial features of cooperation within a division of labour.

5.2. Elements of an ethnographic approach:

One value of ethnographic work is that it draws attention to the relationship between an artifact and the context within which it is used. Our primary emphasis has been upon the way in which the Fault Report Form is embedded within the organisational structures, project arrangements and intra-team gatherings of a project. The particular focus was upon the role of Fault Report Forms as representational devices, which were used to provide partial displays of 'the state of the project' and to exhibit the pattern of problems being encountered in the project's testing work, and to identify the specific faults of the machine design and of particular machines.

The FRFs were mediating devices. They provided a means of communication between the test operators and the project engineers, making available to the problem solving investigations of the latter specific and rich details of machine failures (cf. Button and Sharrock 1993). The information for the engineers provided in the FRF and elaborated in the Sunrise meeting was further mediated to other engineers on the project through the attendance arrangements whereby participants in the meeting were representative of project sub-groups. The FRF's were used to reduce the amount of 'in person' participation necessary amongst those whose time was valued and whose work load was invariably close to its practical limits. (cf. MAN-3-3)

The FRF was used to organise the Sunrise meetings. The summary of the FRF forms provided an at-a-glance cumulative view of the results of the previous days test work and an initial survey of the range of 'faults' now being encountered. The ordering of the fault reports in sequence according to machine age and form number provided a sequencing guide to the meeting's topics, and the reading through and discussion of the detail of individual FRF's provided the topical substance and progression of the meeting's main business. The materials provided in the FRF were the occasion for talk within the Sunrise meeting and were the materials for the provisional analysis and diagnosis of machine problems.

We have also emphasised the extent to which the FRF is embedded within the distribution of knowledge in the project. In ethnomethodology's jargon, the relationship between the FRF and its organisational setting is a mutually elaborative one. The FRF is intelligible and plausible only on the basis of a diffuse knowledge of the organisation of the project's working ways and the (often immensely detailed) history of the exigencies which it has encountered. The determination of what the FRF actually means, and of what it might show with respect to the true nature and actual cause of the problem which it reports, requires appeal to what its readers know about the way in which the project and, in particular, its testing operations are organised. That the report form could actually be saying a certain thing, having a definite meaning, would be decided on the basis of what could conceivably be the case under the conditions of project organisation - its sense was characteristically there to be seen or to be found through close and repeated re-reading and discussion by those who were already familiar with the ways of the project team and the multifarious organisational and technical problems involved in building photocopying equipment. The determination of what the report definitively - or at least provisionally - might mean involved, then, reading it in terms of its relation to the locally known organisation of the work and the report's content provided its readers with further information with respect to the real circumstances of their continuing work - that, for example, a problem which they had supposed to be superceded had now recurred.

5.3. The social distribution of knowledge

The focal concern of the paper has, therefore, been with the writing, reading and interpretation of the FRF, as an expression of the general observation that the users of MOIs must make sense of them and that the MOIs are 'recipient designed' in respect of the interpretive capacities of their putative users. Thus the reading and the writing of FRF's was conducted under the auspices of the organisation and setting, oriented to the reciprocal knowledge that participants have of each others concerns, needs and sensibilities, and with regard for the formal and informal requirements which regulate their relations to each other. We have offered the concept of 'the social distribution of knowledge' as a way of characterising some main features of the situation within which the interpretation of FRF's takes place and of identifying the resources that are invoked to make sense of the contents of these forms.

In the case reported here we have considered how the knowledge necessary to make sense of a MOI was socially distributed within the design and development project we studied. Indeed the team was constructed around a distribution of expertise across various specialisms. Members of the team were sensitive to and aware of this mix of skills. We suggest an interplay between what is known in common and what is unevenly known, what can be assumed of others and what it is specifically hoped that others know while we do not, and we see this interplay as evident in the reading, writing and talking through of the MOIs used in this case.

Two examples of the social distribution of knowledge we reported were (i) that between testers writing the FRFs and the module leaders in the Sunrise meeting reading the FRFs, and (ii) the distribution of knowledge between the different expert module representatives who attend the Sunrise meeting.

In (i) the work of the design project assumes that the testers are able to report details of faults with the prototype machines but that the module leaders in the Sunrise meeting bring different knowledge to their tasks of reading these reports with their expert knowledge and in order to determine the significance of the faults for the project, its overall progress and its chances of success. It is hoped that the FRFs make sense to the module leaders and that they can make sense of them.

In (ii) the experts from different specialisms talk through the FRFs and speak to the problems raised with deference to each other's specialisms but without strict proprietary ownership or responsibility. The different engineer specialists work together, acquire a knowledge of the general character of other's problems and the general problems of photocopier design, subordinate their specialism to the business of problem solving and bring their expertise to bear, if they can, without contending as rivals or being bound within 'mentalities' of their specialism. Problems are solved interactively and are viewed as whole-project issues. When, as often was the case, problems directly effected more than one module then each module had to come to an understanding of what, for the other modules concerned, would be a solution. that is, an understanding of what the different requirements upon a solution were.

The project, and in particular the Sunrise meetings, were organised to facilitate the sharing of the different expert knowledges. The method to facilitate this sharing consisted of a fairly minimal prescription, which was that attendance of a representative from each module was compulsory at each Sunrise meeting. The nature of these meeting was such that speaking to a problem 'outside' of your domain of expertise was not considered a transgression and that participants, over time, acquired a sense of other's problems and the issues at large within the project as a whole. This is perhaps in contrast to more prescriptive practices and mechanisms which more rigidly determine the relevance of particular pieces of knowledge for different members of an organisation or specify who may speak to what issues on what occasions, and so on. In saying this we do not, of course, seek to promote, in the abstract, one method of knowledge sharing above another but rather we simply seek to report the mechanisms being used in this study and as a basis for comparison with other strategies. (Contrast the approach reported here with, for example, the strategy reported in MAN-1-7. In that case information about changes made to specifications of designs was centralised in a department known as 'configuration control' and then redistributed by this department to those which this department determined needed to receive the information and according to models of the articulation of the work that this department followed and deployed).

This paper, then, has sought to identify symbolic artifacts being used in a particular design and development project for the articulation of further project work and sought to describe a number of the practices and strategies involved in making sense of these artifacts as mechanisms of interaction in a context where knowledge is socially distributed.

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COMIC References

Deliverable 2.1

Deliverable 3.1

COMIC-MAN-1-7

COMIC-LANCS-2-4

COMIC- MAN-3-3

The Foss cases

Peter Carstensen and Carsten Sørensen

Risø National Laboratory

When organizations embark on manufacturing complex products, a multitude of actors representing different areas of competence cooperate. Because of the complexity of the work due to, for example, the nature of the product and the large number of interdependent participants, part of their work concerns articulation, e.g., coordination, management, allocation, negotiation. This chapter provides a general introduction to the field study at Foss Electric, a Danish manufacturing company. The field study surveyed a large-scale project involving mechanical, electronic, software, and chemical design of a complex instrument for testing the quality of raw milk. We argue that in this particular project a matrix organization, scheduled project meetings, informal meetings, and paper-based artifacts are the primary means of managing the complexity of articulation work. This chapter serves as a general introduction to the four chapters analyzing the social mechanisms of interaction used at Foss Electric in the S4000 project: 1) The Bug Report; 2) the Augmented Bill of Materials; 3) the CEDAC Board; and 4) the Product Classification Scheme (Section 2.2, 2.3, 2.4, and 2.5).

1. Introduction

A large scale manufacturing project is a very complex human activity involving a multitude of people with different areas of competence. A huge amount of decisions are to be made. The actors are mutually interdependent and they must articulate their activities, i.e. coordinate, allocate, relate, schedule, etc. the activities, actors, resources, etc. with respect to each other (Strauss, 1985; Strauss et al., 1985). People are extremely good at handling complexity of articulating by monitoring each other, and at communicating by means of ad-hoc modes of interaction and conventions from everyday life, cf. e.g., (Heath et al., 1993).

Problems will, however, emerge in highly complex work when, for example: (1) The cooperative work setting includes many geographically distributed actors; (2) there are a large number of intertwined activities, actors, or resources; (3) different areas of competence with different conceptualizations and goals are involved; or (4) the work is carried out over a long time-span. If the participants are not to be engaged in articulation most of their time, different measures can be taken, such as, optimizing the organization of work (Mintzberg, 1979), having structured project meetings, introducing standard operating procedures, etc. In order to reduce complexity, symbolic artifacts are often introduced, e.g. different types of forms, schedules, classification schemes, etc. These artifacts can reduce complexity by stipulating and mediating articulation work (Schmidt, 1993a). The artifacts are always accompanied by conventions or written organizational procedures stipulating the usage. These artifacts will often serve other, more domain specific, purposes as well, besides that of reducing complexity of articulation work.

Much research in the CSCW field have addressed topics related to understanding and supporting the communication among interdependent actors, such as ethnographic studies of how interaction is organized, e.g., (Hughes et al., 1992; Heath et al., 1993); support of real-time high bandwith communication and Media Space, e.g., (Benford and Fahlén, 1993; Ishii et al., 1993); and modelling the communication, e.g., (Flores et al., 1988). Although most of the empirically studies in the CSCW field analyze work settings involving many interdependent actors, they primarily focus on the work of relatively few. Furthermore, the domains investigated are most often characterized by a high degree of monitoring and regulating (often time-critical) activities among the actors, e.g., (Bentley et al., 1992; Heath and Luff, 1992; Fillipi and Theureau, 1993; Heath et al., 1993).

This study addresses manufacturing in general and cooperative aspects of engineering and software design in particular, similar to other studies such as (Anderson et al., 1993) and (Bucciarelli, 1984). The research documented is based on a field study of a large-scale manufacturing project. It has included activities such as qualitative interviews, project document inspection, and observation. The empirical data is interpreted using theories on complexity (Simon, 1981; Woods, 1988) and by applying the concept of Mechanisms of Interaction (MoI) (Simone and Schmidt, 1993). This article investigates the hypothesis that manufacturing organizations faced with large projects where many participants from different areas of competence need to articulate, invent and adopt artifacts reducing the complexity of articulation work.

Because we study design, the field of work is in a number of ways different from, for example, work consisting mainly of monitoring and regulation activities.

The work we have studied is neither time- nor safety-critical. It has a very important constructive, as opposed to analytical, element since the ultimate goal is to specify an instrument which can be manufactured within a broad range of constraints. Hence, the focus is on cooperative aspects of a design process carried out in a large scale setting, involving people with different areas of competence over a long time span. Apart from obtaining a general understanding of the work performed, the main objective has been to identify and characterize artifacts reducing the complexity of articulation work. Further work will be to design computer-based artifacts reducing complexity of articulation work in manufacturing. Others have addressed and modelled articulation work, e.g. (Holt, 1988; Malone and Crowston, 1990; Kaplan et al., 1992), but not based on empirical studies of artifacts reducing complexity of articulation work.

In the next section we discuss the research approach applied in the empirical study. Section 3 provides a short description of Foss Electric. Section 4 presents the S4000 project. Section 5 characterizes the complexity of the S4000 project, and Section 6 discusses the means applied at Foss Electric in general and in the S4000 project in particular in order to cope with the complexity articulation work of development projects.

2. Research Approach

In order to obtain a coherent understanding of — and to design computer-based tools for — manufacturing, field studies are essential (Keyser, 1992; Siemieniuch, 1992). The aim of our empirically based effort was to analyze cooperative work in manufacturing settings where the participants deal with the complexity and uncertainty of getting from a design idea to determining how to produce the product. We conducted a series of interviews and also observed the project. The interviews can primarily be characterized as open-ended qualitative interviews (Patton, 1980). Eleven long interviews (lasting several hours) and ten small interviews have been conducted, and we have participated in approximately ten project meetings. We have, furthermore, spent about 75 man-hours observing the design and production process. The research approach used in collecting data at Foss Electric can be characterized as qualitative research heavily inspired by both Work Analysis (Schmidt and Carstensen, 1990), and by ethnographic approaches to studying engineering work (Bucciarelli, 1984; Bucciarelli, 1987). The approach is similar to the one applied by, for example, Hansen (1993). Qualitative research implies collecting data by, for example, interviews and observation, with the purpose of capturing the richness of worldly realism, hence potentially jeopardizing the tightness of control (Mason, 1989; Sørensen, 1993). Potentially trading tightness of control for richness of worldly realism can imply that the results of the study looses generality.

The approach for analyzing the artifacts identified in the field study is taken from the concept of Mechanisms of Interaction (MoI) (Schmidt et al., 1993). We define a MoI as *"a device for reducing complexity of articulating distributed activities of large cooperative ensembles by stipulating and mediating the articulation of the distributed activities"* and it is characterized by being a symbolic artifact with a standardized format (Schmidt et al., 1993: p. 110). Furthermore, an analytical distinction between the objects of articulation work is suggested. At an overall level these are: (1) Actors; (2) responsibilities and obligations; (3) tasks, i.e., an operational intention; (4) activities, i.e., an unfolding course of actions; (5) conceptual structures, e.g., classification; and (6) common informational, material, technical, or infrastructural resources. The objects of articulation work can relate to the work environment, the field of work, a wider organizational setting, an can also have references to time and space. A number of artifacts used as means of reducing the complexity of the articulation work in the S4000 project were identified. The results from the field studies has been documented in (Borstrøm et al., 1994; Carstensen et al., 1994; Sørensen et al., 1994).

3. Foss Electric

The field study reported was conducted at the company Foss Electric which develop, produce, and market equipment for analytical measuring quality parameters of agricultural products. Equipment for measuring quality parameters of agricultural products is a highly specialized field. There are only a few companies in the marketplace and Foss Electric is among the largest in the world. The R&D and production is localized in Denmark with subsidiary companies in England and Germany. Sales, service and distributors are spread all over the world. The Foss Electric holding company employs approximately 700 people. The products manufactured are used for measuring the compositional quality of milk (the fat content, the count of protein, lactose, somatic cells, bacteria, etc.), the composition and micro biological quality of food products, and for measuring grain quality. The measurement technologies are typically infrared, fluorescence microscopy, or bacteriological testing. The customers are most often laboratories, slaughterhouses, dairies, etc. Due to the degree of high market specialization, few competitors on the market, and an increasing centralization of laboratories, the innovation towards new, better and faster measuring techniques is one of the most important strategic goals for the company. Research and development are essential activities. Foss Electric has implemented concurrent engineering (Harrington, 1984; Helander and Nagamachi, 1992) yielding integration between manufacturing functions throughout the development process. Hence the organization is very much structured in terms of projects. These projects typically includes specialists with competence in fine mechanics, hardware and software design. In some projects also specialists in optics and chemistry are involved. The development from idea to final product involves a number of intermediate products: (1) A product concept defining the overall architecture and interaction between the involved technologies; (2) a few functional models (mock ups); (3) five to ten prototypes of the instrument used for verifying detailed ideas and designs; and (4) a test series of five to ten instruments in order to test manufacturability of the product. Our field study concentrated on one of the large projects Foss Electric has recently accomplished, the System 4000 (S4000) project.

4. The S4000 Project

The objective of the S4000 project was to build a new instrument for analytical testing of raw milk (See Figure 1). It was the first “system”, i.e. an instrument in which several instruments are integrated and can be plugged in and out, Foss Electric produced. Compared to previous instruments for testing milk, the S4000 system introduced measurement of new parameters in the milk (e.g. urea and critic acid) and the measurement speed was to be improved compared to previous products. The S4000 was the first product with an Intel-based 486 PC build-in. The configuration, control, and operation of the instrument should be made via a Windows user interface, i.e. a graphical user interface and use of mouse and keyboard. The instrument consists of approximately 8000 components grouped into a number of functional units, such as: Cabinet, pipette unit, conveyor, PC, other hardware, flow-system, and measurement unit. More than 50 people have been involved in the project, which lasted approximately 2 1/2 year (for version 1 of the S4000 system). The core personnel, involved in design included a number of designers from each of the areas of hardware design, electronics design, software design, and chemistry. Added to this was a handful of draught-persons and several persons from each of the departments of, production, the model shop, marketing, and top management.

Figure 1: The S4000 system being tested in the Quality Control department.

5. Complexity of the S4000 Project

The sources of complexity in the S4000 project can be characterized by analytically distinguishing between: (1) The field of work, i.e., a conceptual understanding of the work processes and objects, and their interrelations; (2) the cooperative work arrangement, i.e., how work is organized; and (3) the environment surrounding and constraining the work arrangement (Carstensen and Schmidt, 1993). We apply the following analytical distinction inspired by Woods (1988) in order to characterize the dimensions of complexity: Dynamism; many highly interacting parts; uncertainty; and multiple mutually interdependent actors.

Dynamism is often caused from the fact that the work situations are characterized by handling a number of concepts, requirements, etc. that are dynamic by nature, i.e., events can happen at indeterminate times. This might result in change of the problem to be solved. There is, for example, inherently dynamism in mechanical design and process planning at Foss Electric. There is a constant change in the utilization of the production machinery. The use of existing machines is optimized, and new machines are introduced. Thus, the set of manufacturing processes that the production function can offer is constantly changing.

Many highly interaction parts: The field of work constitutes of a large number of interconnected parts, components, concepts, etc. A failure can have many possible consequences, and conversely, a failure can have many possible causes and fixes. In Simon's (1973) terms, the problem is ill structured. In order to reduce the problem space, the actors use heuristics and general strategies. The actual procedure for a concrete decision process cannot be described beforehand. At Foss Electric there is, for example, interaction between hardware and 200.000 lines of software, and between software and the mechanical and chemical processes in the flow and measurement system.

Uncertainty exist in many complex work situations, i.e., the actors are often confronted with missing, incomplete, ambiguous, erroneous and contradictory information (Woods, 1988). The actors have to act on their cooperate judgment. In many work situations the problem itself is not evident (Dery and Mock, 1985: p. 107). Uncertainty is usually caused by external occurrences, or it can arise through failures, noise, time delays, influence of previous events, unclear requirement, etc. from the field of work. In the S4000 project measurement of completely new parameters in raw milk (e.g., urea and citric acid) had to be developed. Also the software controlling the whole instrument was to be implemented as a Microsoft Windows application, an area which the software designers had no previous experience in.

Highly complex work situations are most often handled in a distributed cooperative work arrangement with *mutually interdependent actors*. This involves a number of secondary activities of articulating the distributed activities, such as dividing, allocating, coordinating, scheduling, meshing, interrelating, etc. (Strauss, 1988). Cooperative work settings are often not stable and involve a large, varying or indeterminate number of participants (Schmidt, 1990; Schmidt, 1993b). The S4000 project was a large project involving many actors with different areas of competence. It was significantly more complex than the usual projects. As one software designer stated: *"It has really been problematic that we did not have any guidelines and descriptions for how to produce and integrate our things. The individual designers are used to work on their own and have all the needed information in their heads, and to organize the work as they want to [.] When we started, we were only a few software designers. And suddenly — problems. And ups, we were several software designers and external consultants involved"*. Because of the concurrent engineering strategy, different conflicting requirements is exposed and negotiated early in the manufacturing process. Although this is an overall advantage in relation to the quality of the finished product, it leads to a heavy burden of articulation work in the design process.

6. Reducing the Complexity of Articulation Work

The S4000 project was complex, and one of the most predominant complexity factors was the huge amount of articulation work. There are at least the following four countermeasures reducing the complexity of articulation work in the project: (1) A project oriented matrix organization has been implemented at Foss Electric. Projects are organizational units with the project manager serving as a “head of department” and all participants are physically located in the same area; (2) To ensure the overall goals were met, the project had a whole line of scheduled meetings, some weekly and most twice per month. In the most intense phases of the project 27 different meetings, involving from 6 to 26 participants, were scheduled; (3) Besides the scheduled meetings there were held a lot of unplanned meetings. Typically one or two participants who recognized a problem met; (4) The amount of detailed information that needed to be communicated, coordinated, negotiated, etc., required more formalized measures for the daily operation. Different types of artifacts were used to keep track of the integration or the state of affairs, to schedule relations and dependencies among involved actors, tasks, and resources. Some of the artifacts were invented in the project, some were a result of redesign of previous artifacts, and others were adopted. The most essential were: (1) the form and problems list supporting articulation work among software developers in relation to detection of software errors and -changes; (2) the Augmented Bill of Materials (ABOM) supporting integration between mechanical design, process planning, and production; (3) The CEDAC board (Cause and Effect Diagram with the Addition of Cards) for integrating mechanical design and process planning; and (4) the Product Classification Scheme supporting distributed classification and retrieval of CAD models. These four examples are presented and analyzed in the four chapters in part 2.

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