

Modes and Mechanisms
of Interaction
in Cooperative Work

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Outline of a Conceptual Framework

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Abstract. The interdisciplinary research and development area of Computer-Supported Cooperative Work or CSCW represents a fundamental shift in the approach to the design of computer systems. With CSCW, the very issue of how multiple actors coordinate and integrate their individual activities has become the focal issue for the development of computer systems. In order to develop computer systems that provide adequate and effective support for cooperative work in contemporary flexible work organizations, it is crucial to advance our understanding of cooperative work and its articulation.

The objective of this report is to investigate the different roles of *modes of interaction* and *mechanisms of interaction* in the articulation of cooperative work so as to identify the different support requirements of modes and mechanisms of interaction. In order to do this, a number of empirical field studies is collated, discussed, and compared.

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Table of Contents

Table of Contents	3
1. Introduction	5
2. Cooperative work	6
2.1. The emergent nature of cooperative work.....	8
2.2. The evolutionary character of cooperative work.....	11
2.3. Interdependence in general and interdependence in work	13
2.4. The common field of work	15
2.5. The articulation of cooperative work	18
2.6. The complexity of articulation work	20
3. Articulation of cooperative work: Cases	23
3.1. Manual control: The hot rolling mill.....	23
3.2. Supervisory process control: The nuclear power plant.....	27
3.3. Supervisory process control: The London Underground control room	29
3.4. Air traffic control: The flight strips.....	34
3.5. Production control in manufacturing: The MRP system.....	40
3.6. Production control in manufacturing: The kanban system.....	47
3.7. Portfolio management: The list	50
3.8. Classification scheme: The ICD.....	52
3.9. Administrative procedures.....	54
4. Articulation of cooperative work: Modes and mechanisms.....	59
4.1. Modes of interaction.....	60
4.2. Mechanisms of interaction	64
5. Implications for CSCW systems design.....	68
Acknowledgments	70
References.....	72

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). 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.¹

In so far as 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), CSCW can be taken as a complete overturn of this paradigm (Hughes et al., 1991).

The general objective of the present report is to outline a conceptual framework for the analysis of cooperative work that will assist analysts and designers in several ways, e.g.:

- provide heuristic guidance to analysts so as to assist them in conducting cost-efficient empirical field studies with a view to identifying system requirements;
- support the comparison and transfer and thus the generalization of findings from different empirical field studies;
- provide a frame of reference for conceptualizing, comparing, and transferring user experience with particular CSCW systems;
- assist analysts in conceptualizing empirical findings in terms of requirements, i.e., in a format that is compatible with the issues and concerns of software engineering;
- identify distinct classes of support requirements so as to provide a rational basis for developing architectures for CSCW systems.

More specifically, the objective is to investigate the different roles of *modes of interaction* and *mechanisms of interaction* in the articulation of cooperative work so as to identify the different support requirements of modes and mechanisms of interaction. In order to do this, the report collates, discusses, and compares a number of empirical field studies which have been reported in the literature or in which the author has been personally involved.

The bulk of the report is therefore devoted to a number of case studies of cooperative work in different work domains.

¹ 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).

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 be 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 of 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 (Popitz et al., 1957; Bahrtdt, 1958; Dahrendorf, 1959; Kern and Schumann, 1970; Mickler et al., 1976, for example).

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.”² 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.”

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

“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)

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 yet, 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 people that are mutually dependent in their work and therefore required to coordinate and integrate their individual activities. 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 intrin-

² 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 fuyaient les uns les autres, il faudrait en demander la raison et chercher pourquoi ils se tiennent séparés. Mais ils naissent tous liés les uns aux autres; un fils est né auprès de son père, et il s’y tient: voilà la société 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).

sically 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, on its part, 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 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 simple 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 temporary; 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, cooperative work arrangements in complex environments become arenas 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.’ Even though dubious assessments and erroneous decisions due to characteristic individual biases are transmitted to other decision makers, this does not necessarily entail a diffusion or accumulation of mistakes, misrepresentations, and misconceptions within the decision-making ensemble. 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 the field of work as a whole, the multifarious nature of the field of work 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.

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 interesting 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 multiplicity of the domain and the contradictory functional requirements. 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, any 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 with 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 (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 of the transformation process and the social 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 requirements of the work domain 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.

In view of the fundamental trends in the political economy of contemporary industrial society, 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 to coordinate their distributed activities in a comprehensive and integrated way. 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* 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 are some significant differences, however, that need to be explored. 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 by 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 by 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 on 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) poses contingency 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.

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. Second, the field of work itself is manifold. It comprises, of course, the objects and processes but also the sensors and effectors as well as the more complex tools and control mechanisms that has been inserted between the actors and the objects and processes. In addition, the field of work may comprise the repertoire of material resources and technical artifacts (data bases, inventories and other repositories, buildings, infrastructures) by means of which the production process is performed. Third, the production process will be carried out in a wider work environment with specific constraining characteristics and operational demands (commercial, economic, environmental, legal requirements and constraints). Fourth, in the contemporary system of social division of labor, 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 of other cooperative work arrangements (e.g., administration, ethnographic studies, and systems engineering). In the social division of labor, the field of work for some ensembles may even be collections of data: the archives of administrative agencies, for example, may be the common field of work for the staff of the registry; the global collection of data on causes of deaths is the common field of work of doctors, authorities, and other parties maintaining and using the International Classification of Diseases.³ And fifth, the boundary and character of the field of work changes 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

³ See the discussion of the ICD below.

and bank effects), which rely upon indirect and inferential information sources (thus, more complex interactions are fostered).” (Perrow, 1984, p. 182).

The concept of a field of work has been analyzed — under different labels — by a number of researchers in empirical and theoretical work analysis.

First and foremost, Charles Perrow (1984) 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 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 Table 1 and Table 2:

Complex versus Linear Systems

<i>Complex Systems</i>	<i>Linear Systems</i>
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)

Table 1. Aspects of complex versus linear systems (Perrow, 1984, p. 88).

Tight and Loose Coupling

<i>Tight Coupling</i>	<i>Loose Coupling</i>
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

Table 2. 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. The emphasis on Risk as a separate dimension again reflects the class of domains Cognitive Engineering research primarily addresses. For our purposes, Risk can be seen as one among many demands and constraints posed by the work environment in general (along with, say, flexibility, resource economy).⁴ In the context of cooperative work, the effect of Risk is to make the field of work tighter coupled (because actions are irreversible under constraints of Risk). Uncertainty, on the other hand, is of significant importance to the formation and articulation of cooperative work arrangements.

The field of work of a particular cooperative work arrangement can thus be characterized along the following dimensions.

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:

“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)

When the field of work encompasses subsystems that are complex objects in their own right, cooperative work will involve multiple representations and conceptualizations of the domain. Thus, the decision-making process requires employment of, and 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 or by being more or less tightly coupled and hence time-critical.

“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)

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, misleading etc. information.

“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)

⁴ The work environment in the wider sense, that is, the demands and constraints that are not directly posed by the field of work but rather characterize the conditions under which the demands and constraints directly pertaining to the control of the field of work must be met. We will simply refer to this ‘second order’ environment, the work environment in the wider sense, as *the work environment*.

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*. This distinction is fundamental to CSCW. As noted in the introduction, the core issues in the design of conventional computer-based systems for work settings 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).

The booking system of an airline, for example, 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. The seating arrangements of the different flights and the database model of it constitutes the field of work of the booking agents. Thus, the operators of the booking agents cooperate by changing the state of the field of work, in casu, by blocking (or releasing) seats. The system does not in any way support articulation work, apart from providing a simple access control facility. In this case, 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 probably quite sufficient for the job.

Thus, in many cases the articulation of the different activities of different actors in relation to the field of work (or in relation to the model of the field of work as incorporated in the computer-system) is not a problem for the designer. In order to develop computer-based systems that support the articulation of cooperative work, however, this issue comes to the fore. The distinction between doing the work and articulating the work is therefore essential to CSCW.

2.5. 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.”

Articulation of cooperative work is thus required with respect to multiple “salient dimensions” (Strauss, 1985): who, what, where, when, how, etc.? A tentative inventory of the salient dimensions of articulation work could look as follows:

(1) Articulation in terms of **actors**, that is, the actual or potential participants in the cooperative effort whose cooperative activities are being articulated (in different capacities such as roles, jobs, individuals, collectives): Which partners are potentially relevant for a particular project in terms of skills, competing commitments etc.? Who are available when?

(2) Articulation in terms of **responsibilities**, that is, in terms of general accountability (obligation, commitment).

(2) 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 tasks (procedure, workflow)?

(3) 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?⁵

(4) Articulation in terms of **conceptual structures**, that is, in terms of the relationship between categories used within a specific community as ordering devices: definition, classification, prototypical, causal, genetic, historical, means/end relations.

(5) Articulation in terms of common **resources**:

- **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, bandwidth)?

Furthermore, articulation work is never done in the abstract, it is always done in relation to and in terms of a wider context:

- the state of **field of work**;
- the demands and constraints as posed by the **work environment**;
- the wider **organizational setting**.

And, finally, articulation work is, of course, done with reference to abstract systems of reference: **time and space**.

It goes without saying that these dimensions of articulation work are interdependent. For example, articulation with respect to tasks may refer to actor, various resources, the field of work etc. and the tasks, actors, resources etc. may themselves be defined, classified, etc.

Compared to such terms as ‘coordination’ or ‘conversation for action’, the concept of articulation work provides a number of benefits 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 al-

⁵ The terminology used here comes from the Scandinavian tradition: 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)

location of resources. It connotes, for instance, monitoring, handing over, resolving inconsistencies, reconciling incommensurate assumptions, opinions, and beliefs, and so forth. Second, articulation work specifically refers to the articulation of distributed interdependent activities required when multiple actors are engaged in cooperative work. That is, it does not necessarily encompass the coordination of “multiple, interdependent activities” performed by only one actor.⁶ 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 and Flores, 1986) is what it 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.

2.6. The complexity of articulation work

The very fact that multiple actors are involved in doing the work introduces an essential element of distributed decision making.

The contingencies encountered in any human action may defeat the very best plans and designs. As pointed out by Suchman (1987, p. 38), “the relation of the intent to accomplish some goal to the actual course of situated action is enormously contingent.” Plans may of course be conceived by actors prior to action but they are not simply executed in the actions. Action is infinitely rich compared to the plan and cannot be exhausted by it.

Accordingly, even in the most mundane 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 coopera-

⁶ 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 are interdependent and have to be coordinated.

tive 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 contingencies, criteria, methods, specialties, perspectives, heuristics, interests, motives, and so forth.

Now, 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. As an integral part of cooperative work, articulation work arises as a set of activities required to manage the distributed nature of cooperative work.

In order to account for the distributed nature of cooperative work, Gerson and Star (1986, p. 266) 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, unanticipated 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.”

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.

For example, when Suchman (1987) posits that “the relation of the intent to accomplish some goal to the actual course of situated action is enormously contingent”, this statement is overly general and exaggerated. Action to accomplish some goal is not *always* “enormously contingent”! Of course, any action may be construed as enormously contingent in Herakleitos’ sense that every situation is unique. But the action is not necessarily “enormously contingent” to the actors themselves. Contingencies may be more or less complex to deal with, more or less serious in terms of effect, scope etc., more or less frequent, and so forth, and different contingencies may affect the outcome of action and the validity of plans differently.

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.

The more distributed the activities of the cooperative work arrangement, the more complex the articulation of the activities of that arrangement.

3. Articulation of cooperative work: Cases

A cooperative work relationship is constituted by the fact that multiple workers are interdependent in their work. In other words, they are working on 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 worker — A — is doing is of import to B and C and they can to some extent infer what A is doing from the changing state of the field of work.

While articulation of cooperative work via 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 and mechanisms of interaction* that are combined and meshed dynamically in accord with the specific requirements of the unfolding work situation and the means of communication available.

In the following sections we will present a set of cases that represent different pertinent modes and mechanisms of articulation of cooperative work.

3.1. Manual control: The hot rolling mill

In modern industrial plants, cooperative work interaction is typically mediated by complex machine systems and sometimes the setting even prevents direct communication between agents. In such settings cooperative work can, so to speak, be observed in its basic form, in the nude: cooperative work solely mediated by the changes to the common field of work. A case of such settings is therefore the best place to start our analysis.

The classic study by Popitz and others (1957) on 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.⁷

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 (see 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°.

⁷ 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.

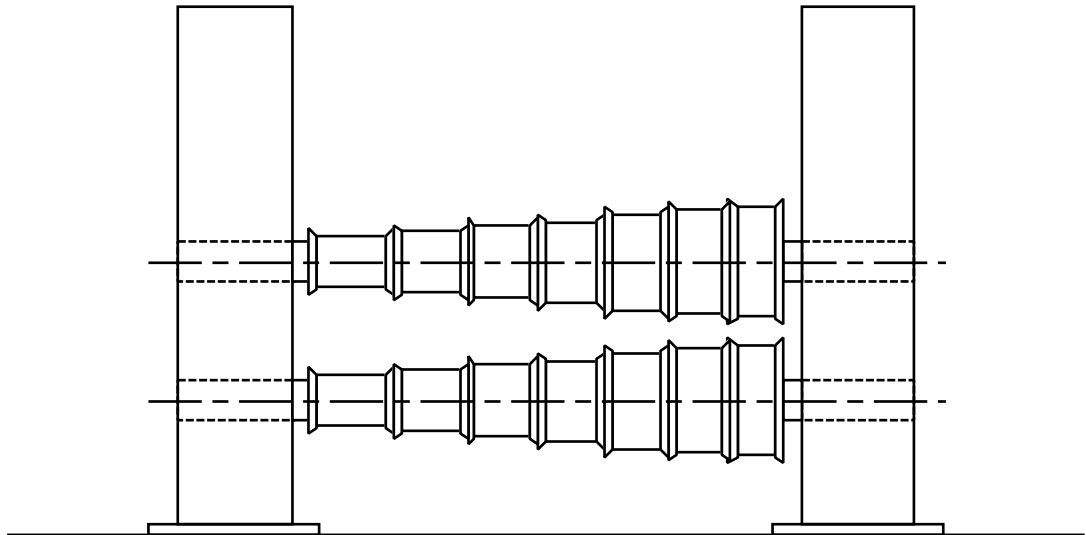


Figure 1. Cross section of the rolling mill stand showing the two six-caliber rolls. When being shaped, the strip is subjected to multiple passes at each caliber whereupon it is shifted to the next caliber, from left to right. The distance between the rolls is adjusted between each pass by the driver.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

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.

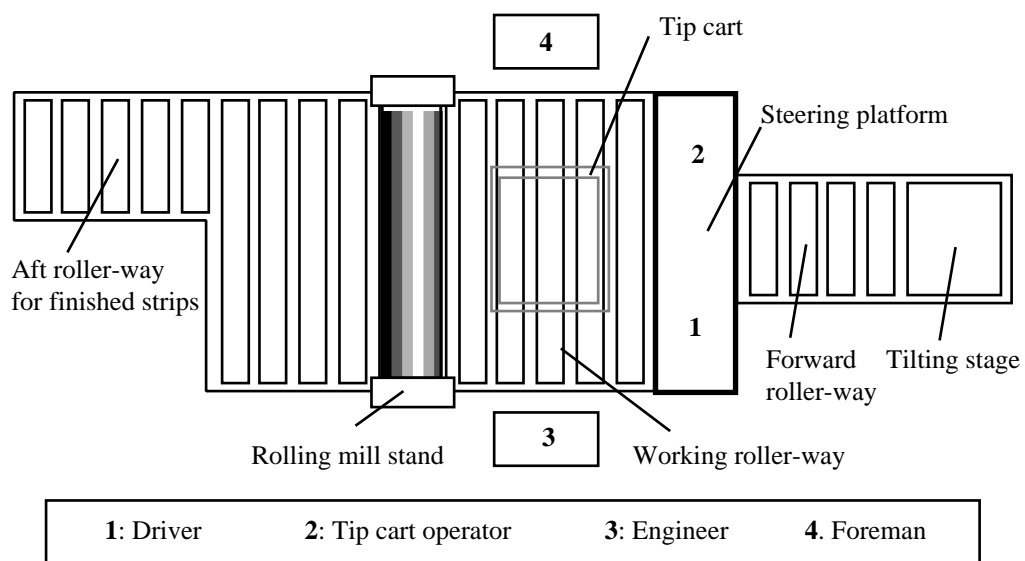


Figure 2. The rolling mill seen from above. (Popitz et al., 1957)

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 rolling-way area after the stand.

The driver controls the tilting stage and the forward rolling-way that moves the incoming ingot forward towards the rolls. His main task, however, is to control the rolling-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 rolling-way in the area after 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.

When the strip has to be tilted for another pass at the same caliber, it must be done while the it 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 senses 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 rolling-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 and it may have to be discarded. In the worst case, the rolls may break which amounts to an enormous 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 continuity 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 rolling-way and move it back to the rolls. The engineer then has to reverse the rolls in order to receive the strip. If 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 until the strip has to be tilted and that it will take longer until it can be shifted to the next caliber. The engineer also apperceives the situation immediately 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 require participants to socialize beyond the immediate interaction.⁸ 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 way without verbal communication and without watching the operations of each other. Each of them know what the other is doing by apperceiving the behavior of the mill: the movement of the rolling-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 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 continuously and intensely by the others — *by way of* the behavior of the strip and the mill.

In sum, then, 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.

⁸ 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).

- (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.
- (3) The operators cannot leave their stations during work. None of them can oversee the process as a whole from their respective stations. To a large extent, they have to rely on indirect evidence (vibrations, light intensity, glow). The operators are thus highly interdependent.
- (4) The cooperating workers are — for all practical purposes — unable to coordinate their individual activities by talking to or watching each other.
- (5) The crew nevertheless manages to act in a concerted way 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.
- (6) 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.
- (7) However, the changing state of the field of work is a perilous channel of articulation work because state changes in the field of work are rudimentary as a means of communication: The bandwidth is quite restricted; the turn-around time of the interaction is determined by the frequency of state changes in the field of work, and — most importantly — the message is completely embodied in the state of the field of work. A state change is never undertaken to send a message. In fact, 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. 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.

3.2. Supervisory process control: The nuclear power plant

In the control of highly complex and automated processes, the cognitive 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 the Primary and Secondary systems between the operators — is far more flexible.

Since the plant is a highly integrated technical complex, the activities of the two operators are complementary and interdependent. In fact, “two operators are really needed to control the process” (p. 281). Therefore, in order to carry out their work, they must act in a highly coordinated fashion, and to do so each of them needs access to reliable information on the state of the plant.

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 two operators both work. By contrast, in the S3C control room design each operator has a computer workstation. While these workstations provide access to all relevant control data, S3C has some disruptive effects on the articulation work required to control the plant. At the beginning of the session, the operators normally agree on the allocation of the Primary and Secondary systems. However, during 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.⁹

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

In sum, then:

- (1) 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 transformation 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)
- (a) 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.
- (3) 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

⁹ 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).

any given time is therefore essentially invisible to the other. This impedes the formation of the reciprocal awareness required for articulation work.

- (4) 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.
- (5) 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 others movements, they are able to communicate verbally and visually. They are thus able to negotiate in ambiguous situations.

3.3. Supervisory process control: 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, amongst 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 others 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 DIA require extremely close collaboration. 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 milieu 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 other is doing but involves 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 available to a co-participant. 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.)

As a 'mechanism of interaction', 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 in 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. Thus the distributed management of the timetable may give rise to inconsistencies in the cooperative operation of the line. It is thus "critical that the DIA and others receive information concerning changes to the timetable, otherwise they will not only misunderstand the current operation of the service, but take the wrong courses of action" (p. 73).

The operators — in casu the Controller — handle 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 through 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 out 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 operators have a variety of means of monitoring the state of the field of work: automatic (the fixed line display), semi-automatic (CCTV) and manual (time tables). Due to their adjacent positioning, they are thus to some extent able to develop a reciprocal awareness by visually monitoring each other’s activities.
- (3) 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.
- (4) 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 to each other’s conversations over telephone or radio.
- (5) 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.
- (6) The large-scale cooperative operation of the Bakerloo Line as a whole is basically managed by means of a timetable. As a ‘mechanism of interaction’, the timetable requires continuous 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.

3.4. Air traffic control: The flight strips

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 is not feasible, however, 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 contrast, 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.¹⁰

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:

“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 a complex cooperative work arrangement with an elaborate and dynamically changing system of division of labour. .

¹⁰ “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).

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 3).

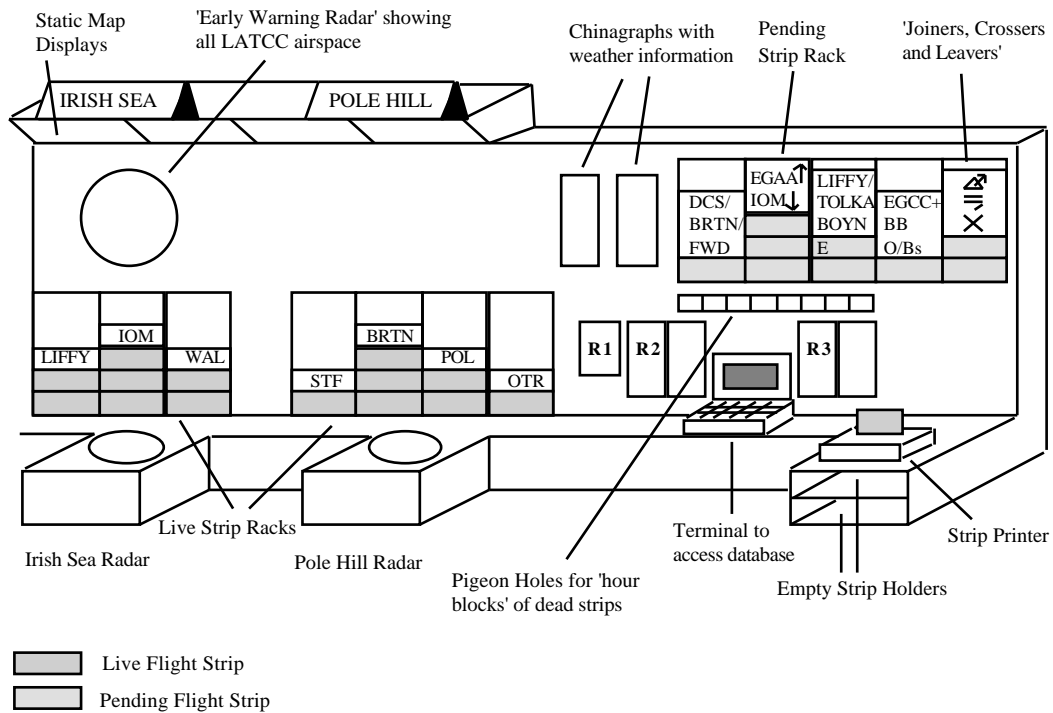


Figure 3. Layout of an en-route suite: Pole Hill and Irish Sea sectors. (Hughes et al., 1992)

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 4). 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 its 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 themselves separated by fixed markers representing particular navigation points in the sector.

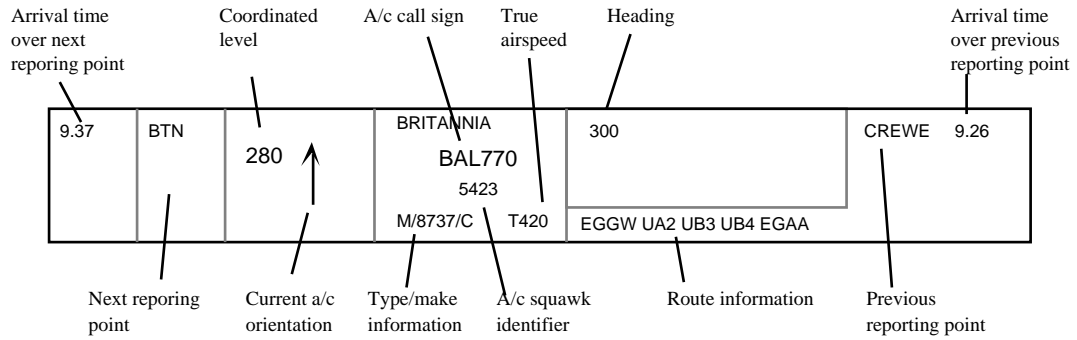


Figure 4. A flight progress strip.¹¹

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

¹¹ Graphics made by the author on the basis of a photocopy of a specimen provided by the Lancaster group.

new flight level is attained, the controller marks a check beside it. Changes in heading, estimated time of arrival, route, call sign, etc. are dealt with 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 work of the operators of the hot rolling mill is 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 assess 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 a 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).

3.5. Production control in manufacturing: The MRP system

In 1990, Bjarne Kaavé conducted a study of cooperative production control in a manufacturing company we can call Alpha.¹² 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 Alpha 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.

The operation of the plant involves a large number of different kinds of interdependent activities. The overall organization of the plant reflects this by being decomposed into a number of functional departments:

Shaping is a plant of its own. There are about 150 workers handling seven different types of processes.

Paint shop is working as a conveyor, where all parts are led through the paint cabin. They paint with five different colors, two colors covers about 85% of the parts, and a change of color takes two hours. Effectiveness depends only of the numbers of shifts from one color to another.

Sub-assembly employs about 25 workers, each handling a number of different assembly tasks. They work in series less than 50, and set up time for each task is negligible, but effectiveness rises with longer series.

Assembly is making the units according to the customers orders. In final assembly, each worker produces a complete unit from all the different parts and sub-assemblies. All fitters can handle more than one type of model, and the problem is not the set-up time, which again is negligible, but the fact that the number of errors increases if the fitters have to change model frequently.

Testing of a unit can be seen as a time delay, and the only management problem here is to choose the right sequence for testing the units.

Packing and Shipping. The units are shipped from the packing department, and the hard problem here is which customers orders to fulfill first.

A strategic decision made by Alpha in 1974 resulted in a very rapid change from production of one single model to production of several models (see Figure 5). The total number of models and variants are approximately 100. This shift in strategy dramatically changed the conditions of production control from that of a forecast-driven, production-for-inventory oriented strategy to an order-driven, ‘just in time’ strategy. Thus, the reference point in the planning process changed from number of units on stock to the time necessary to fulfill current customer orders. The company is now committed to a delivery time of three weeks.

¹² This section 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.

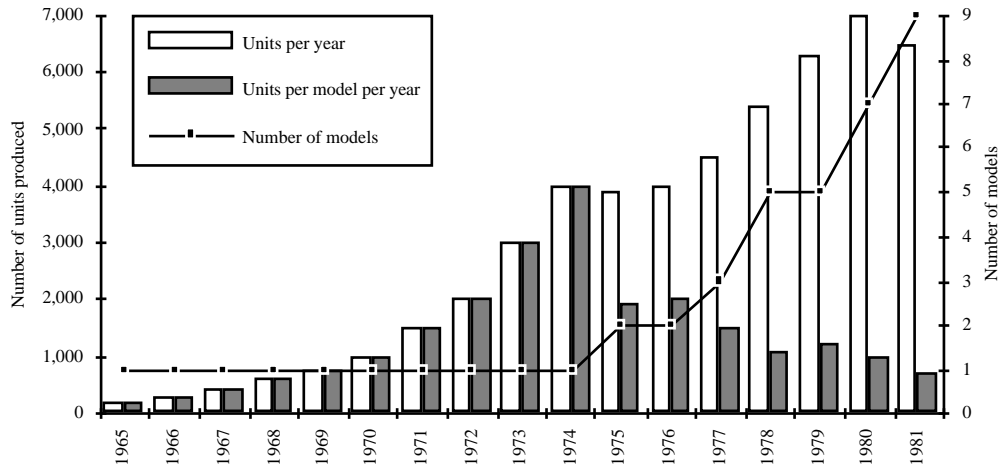


Figure 5. In 1974, company Alpha made a strategic decision to shift from production of one single model to production of several models. (Adopted from Barfoed (1982)).

Kaavé’s investigations in Alpha provided an interesting case of how a conventional production management system — an MRP II or Manufacturing Resource Planning system¹³ — is appropriated and used cooperatively in controlling a manufacturing operation with characteristics far beyond the valid application domain of the system.

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;
- 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). 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.

¹³ In casu, the COPICS system from IBM (IBM, 1972).

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 mediated 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 appropriation 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 Table 3). 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, $\frac{5}{16}$ × 24 × 1”	2
30751	Nut, $\frac{5}{16}$ × 24	2
22479	Washer, flat, $\frac{5}{16}$	2
22842	Washer, lock, $\frac{5}{16}$	2
16935	Clamp assembly	1
88327	U bolt	1
30750	Nut, self-lock, $\frac{5}{16}$ × 24	2

Table 3. 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 6). 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.

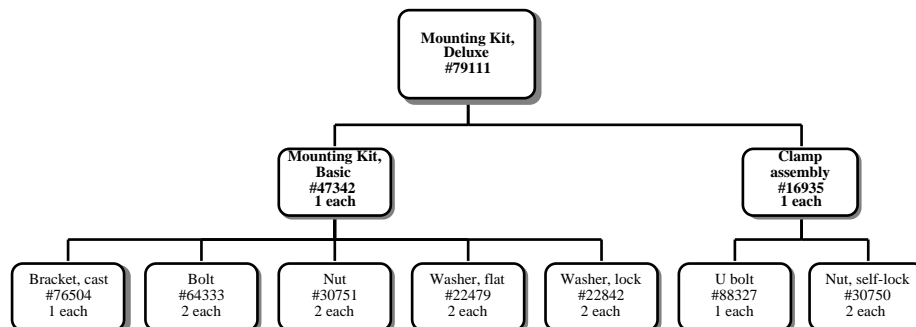


Figure 6. Product structure for part #79111 (Gunn, 1981, p. 15) showing the two-level hierarchy of parent parts (assemblies) and dependent parts (parts and sub-assemblies).

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 Table 4). 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	
		<i>Subtotal, dept. 100</i>	2		12
200	Assembly	Work station 210		4	
		Work station 270		2	
		<i>Subtotal, dept. 200</i>	3		6
300	Crating	Work station 350		2	
		<i>Subtotal, dept. 300</i>	1		2
<i>Total</i>			6		20 hours

Table 4. 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 7).

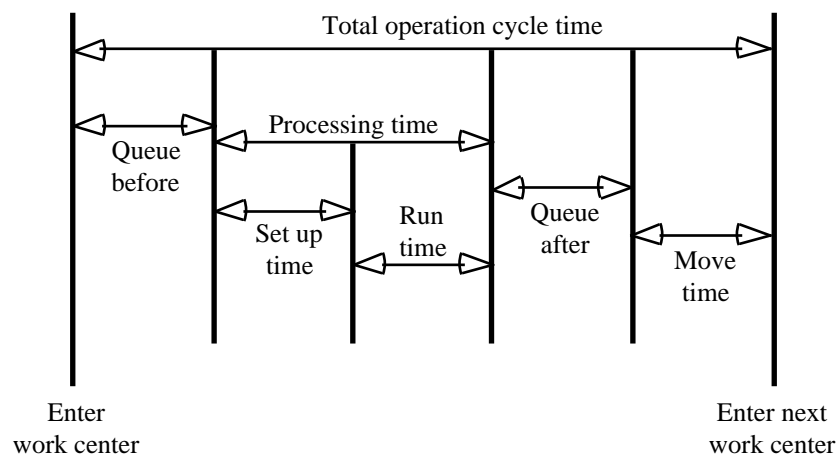


Figure 7. Elements of total operation cycle time (Gunn, 1981, p. 26).

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 dependent parts needs to 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 or dependent parts based on the due date of the orders of the end or parent item as well.

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 it 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 results 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 Alpha 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 Alpha is used to generate production orders. In addition, it is used in order to record production orders that have been accomplished and to ensure that operators are paid when a production order has been carried out.¹⁴

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.

¹⁴ The blue collar workers at Alpha are paid on the basis of a negotiated piece rate tariff.

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 Alpha 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. As reported by Kaavé:

“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 Alpha to use the MRP II system in a manufacturing operation that is basically order driven — as opposed to inventory driven — is the models of pertinent interdependencies of the manufacturing operation at Alpha: 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:

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 the 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 MRP II 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:

<input type="checkbox"/>	Has been printed
<input type="checkbox"/>	In the rack
<input type="checkbox"/>	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.¹⁵

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.

¹⁵ The engineers are allowed to choose 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 enable them to make a handsome wage. Their choice of job is to be approved by the foreman in order to ensure that the engineer does not skip rush orders for the sake of maximizing his income.

In sum, then:

- (1) In the company we have called Alpha, the MRP II-based production planning system is used in a control mode based on actual customer order as opposed to a mode of control based on reliable forecasts of demand. The MRP II system is thus used in a context far beyond its valid application domain.
- (2) The MRP II-based system used nevertheless to (a) to coordinate the mass of activities that need not be handled manually; (b) to coordinate the execution of customer orders well within the projected average demand; (c) to compute and counteract the 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.
- (3) 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.
- (4) The MRP II-based system as used in Alpha company has been redesigned so as to support its use as a mechanism of interaction: By introducing a manually controlled '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 coupling between the state of the field of work for the cooperative production control activities and the representation of the state of the field of work in the MRP II system has been made visible and accessible to those concerned.

3.6. Production control in manufacturing: The kanban system

The Alpha company studied by Kaavé provides another example of a mechanism of interaction in cooperative work: The kanban system.

In company Alpha a *kanban* system is used in certain processes 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 decoupled by buffer stocks. Most metal parts are going through more than five processes before the assembly process.

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 8). A particular card is attached to a container used for the transportation of a lot of parts or sub-assemblies between work stations. When the operator has processed a given lot 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 he has now been issued a production order.

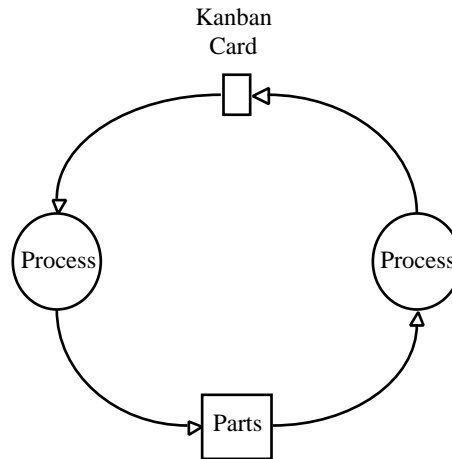


Figure 8. The basic 'syntax' of a kanban system.

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

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

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 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 decision makers to anticipate disturbances and to obtain an overview of the situation. They are enveloped by an overwhelming and inscrutable automatic coordination mechanism.

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 Alpha is faced with extreme fluctuations in demand, operators constantly 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.

This is possible because an informal network of clerks, planners, operators, fork-lift drivers, and foremen in various functions such as purchasing, sales, production, ship-

ping etc. cooperate directly in controlling 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 coordination. The cooperative ensemble has 'appropriated' the *kanban* system in order to increase its flexibility. They have thus taking over control of the system, and are controlling the production far more closely and effectively than warranted by the *kanban* system. This is possibly 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.

It is important to notice, that the 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 would make it impossible for the operators to change the set-up contingently.

In sum, then:

- (1) The *kanban* system is a mechanism of interaction in the sense that it is a symbolic artifact that it used to reduce the complexity of articulating a large number of different cooperative work activities.
- (2) As the MRP II-based system discussed in the previous section, the *kanban* system only serves as a mechanism of interaction because it incorporates (implicitly, in the configuration of the system) a model of pertinent features of the manufacturing operation.
- (3) 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.
- (4) In order to be usable in a setting like Alpha, the *kanban* system must to be managed (monitored, adapted, modified) continuously. This is facilitated by the formation of a network of operators who keep each other informed about the state of affairs.
- (5) The *kanban* system is tied to the field of work in such a way that state changes to 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.
- (6) The design of the *kanban* system as a mechanism of interaction allows operators to manage the system in so far as the control of the execution of the mechanism 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 procedure in some way. That is, due to the operator's control of the execution of the *kanban* system and the fact that they exercise that control, the direct coupling of the system to the field of work has been severed.
- (7) The information ultimately conveyed by the propagation of card up-stream has been filtered and distorted by the successive translations along the line. The *kanban* system does not provide facilities allowing decision makers to anticipate disturbances and to obtain an overview of the state of affairs up- and down-stream. They are enveloped by an overwhelming and inscrutable automatic coordination mechanism.

3.7. Portfolio management: The list

A portfolio management agency investigated by the author in 1987 (Schmidt, 1987) provides an 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.



Figure 9.

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 continuous 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. The 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,¹⁶ 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.

¹⁶ Which is what the headquarters of the bank planned to do at the time.

- (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) Continuous 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 intensive daily contact and, intermittently, spontaneous debates and negotiations between analysts and consultants.

3.8. Classification scheme: The ICD

Like the list in the portfolio management agency, 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 been 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 de-

sign 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)

In sum, then:

- (1) 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.
- (2) The adoption of a standard format does not alleviate the conflicting demands and needs. The problem recurses. The list is subjected to cooperative management — by the committee as well as by the data providers and users.
- (3) The design and management of the list adapts to the conflicting demands by carefully finding “the appropriate level of ambiguity”.

3.9. Administrative procedures

Suchman gives a detailed account of the role of administrative procedures in an accounting office. The accounting office studied by Suchman (Suchman, 1983) 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, the "smooth flow" of paper on a given purchase the following sequence "occurs":¹⁷

- (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 highlights one specific routine complication. It may be the case that the items on a given purchase order are 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, K, and the accounting supervisor, R. K'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 facility, 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 this case, however, the record of what happened presents its own troubles.

Up to the point in the work where the following the transcript starts, a search of the files has produced the following discrepancies:

- (1) The original purchase order is missing.

¹⁷ The 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.

- (2) A completed receiving document is found. There 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 items 3 and 8 as paid. There is no invoice or record of payment for 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.
- (3) 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.

It appears, then, that there are in fact *six* items whose payments are due (1, 2, 4, 5, and 6 and 7.) At the same time, the vendor reports that the past due invoice (for items 6 and 7) is the final payment, and the receiving department reports all the items received. At L256-57 of Suchman's transcript, on the basis of their work together to this point, K and R agree that there must be, somewhere, another record of payment for items 1, 2, 4, and 5.

Sequence 1

L255 R: There's another purchase order some-
 L256 I mean there's another payment somewhere?
 L257 K: Yea, there's got to be another.
 L258 R: There's another payment somewhere,
 L259 now where is that? Is the question.

R and K agree here that there is a missing record of payment on items 1, 2, 4, and 5; the location of that record becomes, accordingly, the question to be answered and the direction for a search.

Sequence 2

L260 K: The only thing I can think of is that it's:
 L261 R: Where's their (paid) folder.
 L262 K:
 Let me go get the whole folder,
 L263 R: Why don't you.
 L264 K: and maybe if I: go through the control numbers (*inaudible*)
 L265 (*she goes to paid invoice files*)
 L266 R: Yea, that's what we're gonna have to do
 L267 we have to look at that whole folder.
 L268 K: (*returns with folder*) The only thing I really was goin' on
 L269 was the P.O. number, cause I didn't have any invoice numbers,
 L270 or really) any dates, to go-
 L271 to find out when it would have been paid
 L272 R: (*looking through folder contents*)
 L273 What purchase order are we dealing with?
 L274 K: 36905.
 L275 (*pause while R leafs through folder*)
 L276 K: What's weird is, though, the girl was telling me
 L277 this number that comes after this, (*number on the past due invoice*).
 L278 That tells you this is the third invoice,
 L279 for this like P.O.
 L280 [
 L281 R: billed on that P.O.
 L282 K: But if that's true, this is one (*invoice for item 3*), that's two
 (*invoice for item 8*), and this is three: (*past due invoice for items 6 and 7*)
 L283 Then there might not *be* another bill.
 L284 R: (*inaudible*) Is that (*the missing P.O.*) in that problem pile up there
 anywhere?

L285 K: No, I don't recall seeing it, but I'll double check on it
L286 ((getting stack from upper shelf))

At L272, the accounting supervisor R begins what proves to be an extensive search of the record of past payments to the vendor, while the auditing clerk K re-examines the set of documents already in hand. At L276-83, informed by her talk with the vendor, K pulls out one detail that seems somehow related to the question of the record's completeness. R's completion of K's remark at L281 demonstrates that he is listening, but at L284 R leaves K's comment without remark and continues with a new question which temporarily brings K away from the invoices and back to the missing purchase order.

Their work is proceeding along two more or less independent lines, with R searching the record of past payments while K continues to study the documents already pulled from the file, when K makes a discovery:

Sequence 3

L333 K: Huuuh.
L334 R: Hmm?
L335 K: Look at ((invoice for item 8)) missing page 2.
L336 R: Where do you get that at?
L337 K: Page 2.
L338 R: Page 2? It's a two page pur- two page, uh invoice?
L339 K: Oh no, oh no. (You're not gonna like this.)
L340 R: know I'm not gonna like it. I already don't like it,
L341 K: Okay,
L342 R: I'm having to look at it, that's making me not like it.

In spite of the split in their attention, which begins with R's search of the paid folder, K and R are each "continually producing comments that, as assessments of what each is finding, allow the other to monitor their joint work" (p. 325). In other words, in exactly the same way as the operators of the Bakerloo Line control room and the air traffic control operators, they are developing and maintaining a reciprocal awareness by making their individual activities publicly visible and at the same time monitoring each other's activities. K and R's continual monitoring of each other provides for their respective searches, at any point, to develop into concerted attention to any of a number of findings.

A little later, K and R turn back to K's finding of the missing page:

Sequence 4

L414 K: Okay,
L415 R: Now then tell me what you see there.
L416 Now I've got that in order ((the paid file)), then we don't have to look.
L417 K: This is page two ((invoice for item 8)),
L418 R: Mmhrn.
L419 K: Okay. We got three of these items ((8)) for \$156,
L420 but all of the tax on them does not equal \$117,
L421 so the page one items: ((items 1, 2, 4, and 5)) go with this invoice ((for item 8)).
L422 That's why ((the vendor)) says this ((invoice for 6 and 7)) is the last item.
L423 R: But you don't have page one.
L424 K: No. ((pause)) Page one isn't there.
L425 R: Thi-this one ((for item 8)) is already paid?
L426 K: Yea, this one's paid.
L427 R: And that's the check for it?

- L428 K: Yea, that- these two: packing slips *((for items 1, 2, 4, 5, and 8))* were attached to the receiver.
- L429 So that was- according to them, we've paid the full amount *((for items 1, 2, 4, 5, and 8))*,
- L430 R: We've paid the full amount,
- L431 K: but we don't: *((laugh))*
- L432 [
- L433 R: But we don't know where page one is.
- L434 K: Cuz this, times tax, just don't: equal up.
- L435 R: Mm hm, mm hm.

At L428-9, K shows how the missing invoice page works to explain why there are two packing slips with the invoice for item 8, one being for items 1, 2, 4, and 5, and R agrees at L430. R immediately offers a next action:

Sequence 5

- L435 R: Mm hm, mm hm. I want you to call that lady
- L436 and tell her you want page one. Of this invoice.
- L437 K: Now at least we have a number to go on,
- L438 [
- L439 R: Tell her that you're gonna do her something *((pay for items 6 and 7))*-
- L440 we're gonna do her something, we want her to do us something
- L441 *((provide the missing invoice page for items 1, 2, 4, and 5))*.
- L442 We need page one for this invoice. All right?
- L443 And then that-
- L444 that explains why all those other things *((1,2,4 and 5))* are not there.
- L445 K: Okay.

Suchman's interpretation of the case is thought-provoking and somewhat contentious:

"Standard procedure is constituted by the generation of orderly records. This does not necessarily mean," Suchman posits, "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).

To be sure, the case shows convincingly that orderly records are not necessarily the result of some prescribed sequence of steps. But the case analyzed by Suchman is a case of *recovery from error* in an administrative agency and provides little, if any, insight into how standard procedures, defined as pre-defined written stipulations, are applied in routine daily work.

It is therefore difficult, if not impossible, to conclude that orderly records are *not* — in normal circumstances where records are complete — the result of some prescribed sequence of steps:

"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)

Suchman's analysis is demonstrably true as far as the error recovery case is concerned, but there is no empirical basis for the quite general claim: "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.”

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 solves the abnormal problem because of their “knowledge of the accounts payable procedure” (p. 322).

In sum, then:

- (1) 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 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).
- (2) Suchman’s case study describes a case of recovery from error in an administrative agency. As such, the case study does not tell us very much about the use of prescribed procedures in routine daily work. What the case does give us, however, is an insight into the crucial role of prescribed procedures even in handling contingencies. The case shows that prescribed procedures convey important heuristic information for the handling of routine tasks as well as errors.

4. Articulation of cooperative work: Modes and mechanisms

The discussion of the different cases of cooperative work in the preceding chapter allows us to outline some salient features of cooperative work and its articulation.

In cooperative work, multiple persons cooperate in the sense that they are interdependent in their work or in other words work 'on' a common field of work, the part of the world that is affected (controlled or transformed) by the work of the actors, e.g.:

- the hot rolling mill as controlled manually by a small number of operators;
- the nuclear power plant and its control system as supervised by the operators in the control room;
- the air traffic in a particular sector of airspace and the concomitant monitoring and communication system at the disposal of the controllers in charge of that sector;
- the manufacturing plant and its myriad parts and processes, orders and workstations;
- the collection of portfolios to be protected and nurtured by the consultants and analysts in a turbulent and complex securities market;
- the global mass of vital statistics to be ordered by a vast and distributed ensemble of doctors and bureaucrats.

The distributed activities of the members of the cooperative ensemble are interdependent in the sense that they — in different ways — contribute to the overall process of control of the common field of work. The participants interact by controlling (monitoring, regulating, changing, transforming) the state of the field of work. Thus, for the participants to be able to contribute purposefully to the cooperative effort, each of them need access to information pertaining to the state of the field of work: *what is the situation, what has happened, what is happening, what might happen?*

Interacting by changing the state of the field of work is an extremely restricted and convoluted way of interaction:

- (1) Changing the state of the field of work, for instance by changing it, is not a symbolic act. It is a real act. It is what it appears to be.
- (2) The allowed changes to the field of work are determined by the nature of the field of work (e.g., the degree of coupling between objects and processes, the extent to which changes are reversible).
- (3) The content of the interaction (the meaning conveyed from A to B) is restricted by the extent to which the changes of the state of the field of work are visible to the others and what they may indicate to the others.
- (4) The turn-around time of the interaction may be determined by the frequency of state changes in the field of work.

That is, apart from rare cases like the hot rolling mill or a booking system where the field of work changes predictably and linearly along a few parameters in an unambiguous way, the common field of work in itself does not provide adequate means for articulating the different contributions of different individuals to the cooperative effort. The need for other means of articulating distributed activities is especially manifest if the state the field of work changes dynamically, unpredictably, non-linearly, if events are ambiguous, if the state of affairs can only be ascertained indirectly, or if disturbances due to deficient coordination of activities could have severe consequences (as in the case of a nuclear power plant or air traffic control).

Thus, while mediation of cooperative work via a common field of work is fundamental to all cooperative work, the articulation of cooperative work requires a multitude of modes and mechanisms of interaction.

4.1. Modes of interaction

As observed above, articulation work is a multi-faceted phenomenon in the sense that work is articulated with respect to multiple dimensions: with respect to the field of work (objects, processes, sensors, effectors, representations etc.) and with respect to actors, responsibilities, tasks, activities, conceptual structures, informational and material resources.

With respect to each of these dimensions, articulation work involves an open-ended repertoire of modes and means of interaction that are meshed fluently in innumerable ways. A few examples will illustrate the point:

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 modes of interaction:

- 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 on between operators of the hot rolling mill, finished 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 modes of interaction involved in articulation work cannot be ordered according to any simple conceptual scheme. Instead, a limited number of salient features of modes of interaction can be highlighted:

(1) **Unobtrusive versus obtrusive:** Modes of interaction can be more or less obtrusive: some modes of interaction such as pointing or tapping at an item or talking or shouting to colleagues are 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). Other modes of interaction 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 modes of interaction 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:

"I 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 reflect 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 bandwidth 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 shows 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 modes of interaction 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 modes of interaction 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.¹⁸

These modes of interaction 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 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 ac-

¹⁸ “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).

tivities 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 bandwidth, 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 modes of interaction 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 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 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).

Written formulations encourage 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.).

(4) Degree of local control: In terms of *stipulation* of articulation work, there is a clear ladder from, at the one end of the spectrum, modes of interaction that do not involve any pre-specified stipulations — to modes of interaction that involve the prescription incorporated in and the active mediation of pre-specified artifacts, at the other end of the spectrum:

(a) Ad hoc articulation (by means of monitoring others, directing attention, embedding cues in artifacts, and negotiating). 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.

(b) Articulation by means of conventions, 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 mutual understanding and the will to adhere to the expectations, supported by various forms of social sanction. That given, it may still be difficult to interpret an action, anticipate the course of the cooperative effort and hold actors accountable.

(c) Articulation by means of stipulations supported by 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 everybody accountable in a far higher degree. The execution of the stipulation, however, relies completely on human recollection and the stipulation is quite open to interpretation (Hart, 1961; Goody, 1986).

(d) Articulation by means of stipulations supported by passively mediating symbolic artifacts, e.g., forms, organizational charts, thesauri, which by imposing a standardized format restricts the ‘degrees of freedom’ each user is faced with. In these cases, the execution of the stipulation no longer relies completely on human recollection and the range of (reasonable) interpretation is relatively narrow compared to, say, statutes.

Goody’s discussion of lists, tables, matrices and other spatio-graphic devices for organizing linguistic items abstracted from the context of the sentence (e.g., in thesauri) is illustrative of this point:

“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.” (Goody, 1987, p. 275).

(e) Articulation by means of stipulations supported by *actively* mediating symbolic artifacts, e.g., time tables, indexing systems for repositories, the ICD, kanban-systems, computer-based scheduling systems (e.g., MRP systems), workflow management systems. Of course, using such a symbolic artifact always requires certain social conventions and skills but in highly complex cooperative work settings these conventions and skills must be supplemented and supported by a mechanism in the form of an artifact, at least to the extent that it provides a plan for action that can be carried out without further consultation and a verifiable (interpersonal and situation-independent) basis for holding actors accountable.

4.2. 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 apparent, 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.

In such settings, the articulation of the distributed activities of cooperative work requires a certain mode of interaction based on a class of symbolic artifacts that *stipulate and mediate* articulation work and thereby reduce the complexity of articulation work. We call these artifacts ‘mechanisms of interaction’.

In order to serve this function, such a device must have the following characteristics:

1. **Artifact:** It must be publicly available in the sense that it does not solely reside ‘in the head’ of human actors (such as conventions) and it must be persistent in the sense that it is available independently of any particular situation. That is, it must exist in the form an artifact.
2. **Symbolic:** It must be possible to manipulate the mechanism independently of the state of the field of work. The artifact incorporating the mechanism of interaction must not be coupled in any strong, tight or irreversible way to the state of field of work. Appropriate manipulations of the device for articulation purposes should be feasible without unwanted side-effects on the field of work. That is, the artifact must have the character of a symbolic artifact.
3. **Standardized format:** It must provide affordances to and impose constraints on work articulation and it must make the state of work articulation at any given moment publicly perceptible.

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.

As a device for the articulation of cooperative work, a mechanism of interaction should be distinguished from other symbolic artifacts regulating human affairs (e.g., signs such as “Stop!”, “Dead Slow!”, “Pharmacy”, “Wine & Spirits”, “Underground”, “Bus Stop”). A traffic light regulating the traffic at an intersection, for example, has certain facilities in common with a mechanism of interaction in cooperative work: It is a symbolic artifact that actively stipulates and mediates interaction. However, the drivers — as drivers — are not engaged in cooperative work; they are, rather, competing for the same resource (the road) and to each and every one of them the others are a mere nuisance. Their interaction is transient and superficial and does not entail the rich multiplicity of purposive reciprocal interactions of cooperative work.

Also, again for the sake of clarification, a mechanism of interaction should be distinguished from the information objects that are ubiquitous in cooperative work settings (such as letters, memoranda, drawings and reports, and the aggregation of such documents in the form of files and libraries) and that help to articulate and mediate distributed activities. Written documents are certainly symbolic artifacts but in so far as they serve to convey information and hence merely provide a medium of communication, they are not mechanisms of interaction. However, managing a complex flow of information objects may require mechanisms of interaction such as standardized formats (e.g., prescribed forms and routing instructions on file covers) and classification schemes (e.g., library catalogues and thesauri).

These artifacts can be conceived of as *mechanisms* in the sense that they (1) are objectified in some way (explicitly stated, artifactual), and (2) are deterministic or at least give reasonably predictable results when applied properly. And they are mechanisms of

interaction in the sense that they reduce the complexity of articulating cooperative work.

As observed above, modes of interaction in articulation work differ with respect to the degree of local control. With a high degree of local control, the different modes of interaction do not impose domain-specific affordances and constraints on the conduct of articulation work. The affordances and constraints of these modes of interaction reflect the ones of the different media: bandwidth, turn-around time, etc. On the other hand, when articulation work is stipulated and mediated by artifacts, the structure of the artifact inexorably embodies domain-specific affordances and constraints. Thus, in order to be able to support the articulation of distributed activities, a mechanism of interaction must represent certain pertinent aspects of the field of work and the organization of the ensemble. Conceptual schemes, for example, are obviously domain specific in that they represent a model of the conceptual structure of a domain. The same obviously applies to organizational structures. Also, the master schedule of a MRP system for production control in manufacturing embodies an elaborate model of the products, their components (Bill of Materials), the average production or purchasing time and cost of each component or subassembly, etc. Likewise, an organizational procedure refers to typical classes of cases characteristic of the particular domain at hand. It may codify ‘good practice,’ recipes, proven methods, efficient ways of doing things, work routines. It may also convey information on the functional requirements to be met by the process and the product; it may highlight decisional criteria of crucial import; it may suggest a strategy for dealing with a specific type of problems (e.g., which questions to address first?); it may indicate pitfalls to avoid; or it may simply provide an *aide memoir* (such as a start procedure for a power plant or an airplane). And, finally, it may express some statutory constraints in which case disregard of the procedure may evoke severe organizational sanctions. In short, mechanisms of interaction like the ones mentioned above are enmeshed in the semantics of the particular work domains.

Mechanisms of interaction are local and temporary closures with a limited area of validity and they are by necessity underspecified. As observed by Gerson and Star, these mechanisms themselves require articulation work:

“Every real world system [...] 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, that *closes the system locally and temporarily* so that work can go on.” (Gerson and Star, 1986, p. 266)

Thus, mechanisms of interaction are not executable code but rather heuristic and vague devices to be interpreted and instantiated, maybe even by means of intelligent improvisation. Mechanisms of interaction are not automata but “resources”: “plans are resources for situated action” (Suchman, 1987, p. 52). This observation applies to mechanisms of interaction in general.

To be made to work, they themselves need to be managed, i.e., constructed, maintained, developed, interpreted, applied, adapted, circumvented, modified, executed, represented, and negotiated. This secondary level of articulation work is, of course, also performed cooperatively (Schmidt, 1991).

At this point, however, some remarks of caution are required. The thesis that “plans are resources for situated action” does not, as yet, provide sufficiently explored conceptual and empirical foundations for designing mechanisms of interaction for CSCW systems. As argued above, the thesis is of fundamental importance to CSCW systems design, but 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 designed artifacts (schedules, procedures, classification schemes, etc.) may support practice.

Plans do not determine the course of action in any absolute or causal sense but different plans in different settings may determine the course of action differently, and in

some settings plans do determine the course of action in a very 'strong' sense (e.g., timetables). These are issues that can — and should — be determined empirically (as opposed to philosophically). That is, for sociological research to provide a conceptual foundation for CSCW systems design a shift in perspective is necessary: What is it that makes plans, schedules, procedures, classification schemes etc. useful in the first place? What makes them 'resources'? 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? 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? What, then, makes one procedure more useful than another for a certain purpose in a specific setting? Which specific features in the designs of existing plans, schedules, procedures, classification schemes etc. make them amenable to their cooperative management and which features represents impediments to their cooperative management? Could a computer implementation of a specific mechanism of interaction enhance the ability of the given cooperative ensemble to articulate its distributed activities in a more flexible, effective, and efficient manner?

These are all researchable questions. That is, far from closing the book, so to speak, the concept of mechanisms of interaction for CSCW systems design opens up a host of intriguing and important problems.

5. Implications for CSCW systems design

Now, 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 platform designs. It is becoming increasingly clear that current platforms in important ways are inadequate as platforms for CSCW systems. They are deficient for CSCW purposes in that they do not adequately support the seamless interweaving of individual and cooperative activities; a vast 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.

(1) 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 work and cooperative work. 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 platform*. That is, CSCW facilities that support cooperative work by supporting various modes of interaction by increasing the bandwidth 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 *platform 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 coop-

erative and individual work breaks down. This applies to single-user as well as multi-user applications.

(2) 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 in items 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 requirements will encroach upon what has heretofore been thought of as single-user applications, such facilities will have radical implications for the design of the operating system of a CSCW platform.

(3) A vast — presumably open-ended — array of modes of interaction is involved in the articulation of cooperative work. These different modes are combined and meshed dynamically, according to the requirements of the specific situation at hand, and they are meshed fluently and, more often than 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 platform facilities and specific applications should be planned and designed carefully.

(4) Since mechanisms of interaction are enmeshed in the semantics of the particular work domains, a 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 thus 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.

The dimensions of articulation work — who, what, where, when, how, etc. — are interdependent and these different aspects of articulation are thus themselves to be meshed in a fluent way. Hence, in order not to impose artificial distinctions and thus disrupt the ongoing articulation work, facilities should be provided that support the linking of different mechanisms (Malone et al., 1992).

(5) It was argued previously that mechanisms of interaction require persistent cooperative management in order to be useful as a means of reducing the complexity and the cost of articulating distributed activities and that this management activity is itself a cooperative activity. We can thus state the following requirements for a CSCW application incorporating a mechanism of interaction (Schmidt, 1991; Schmidt, 1992):

- (1) It should be visible to the members of the ensemble in terms of basic concepts pertaining to the articulation of cooperative work
- (2) It should make the incorporated mechanism accessible to users and, indeed, support users in interpreting the mechanism and evaluating its rationale and implications.
- (3) It should support users in applying and adapting the mechanism to the situation at hand; i.e., it should allow users to tamper with the way it is instantiated in the current situation, execute it or circumvent it, etc.
- (4) It should be ‘malleable’ in the sense that it supports actors in modifying the underlying mechanism and in creating new mechanisms in accordance with the changing organizational realities and needs.
- (5) Since the management of mechanisms of interaction is itself a cooperative activity, the system should support the documentation and communication of decisions to apply, adapt, modify, circumvent, execute, etc. the underlying mechanism.
- (6) And in all of this the CSCW system as a whole, i.e., the CSCW platform, should support the process of negotiating the interpretation, application, adaptation, modification, circumvention, execution etc. of the mechanisms of interaction incorporated in various applications by providing general facilities for enacting and meshing an array of modes and means of interaction.
- (7) Since the system should support cooperative management of the mechanism of interaction, the system should support multiple users in modifying the mechanism of interaction while being immersed in the very flow of distributed activities. This raises a host of problems such as control of propagation of changes and management of (in)consistency.

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 Pages

76

Tables

4

Illustrations

9

References

84

 Abstract

The interdisciplinary research and development area of Computer-Supported Cooperative Work or CSCW represents a fundamental shift in the approach to the design of computer systems. With CSCW, the very issue of how multiple actors coordinate and integrate their individual activities has become the focal issue for the development of computer systems. In order to develop computer systems that provide adequate and effective support for cooperative work in contemporary flexible work organizations, it is crucial to advance our understanding of cooperative work and its articulation.

The objective of this report is to investigate the different roles of *modes of interaction* and *mechanisms of interaction* in the articulation of cooperative work so as to identify the different support requirements of modes and mechanisms of interaction. In order to do this, a number of empirical field studies is collated, discussed, and compared.

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