

Taxonomy for Cognitive Work Analysis

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Abstract. The taxonomy is a conceptual framework for analysis of cognitive activities as they actually unfold in a complex work situation. It has emerged through years of studies in process plants, electronic maintenance workshops, libraries, hospitals, and manufacturing companies. The present approach to a taxonomy is shaped by intention to create a tool that can serve the design of advanced information systems by making it possible to match system properties to the users' actual, cognitive activities, resources, and preferences and to predict the kind of changes to be expected in the behavior of individuals and organizations in response to new information systems.

The taxonomy is, however, also intended to serve needs of research in general in complex work environments. In particular, it is intended to be a vehicle for generalization of results of field studies in various domains so as to make it possible to transfer results among domains.

Accordingly, the taxonomy is shaped as a multi-facet description system along the dimensions of 1) The work domain representation; 2) Activity analysis in domain terms; 3) Activity analysis in decision making terms; 4) Information processing strategies; 5) Actual work organization, the dynamic division and distribution of activities and their coordination; 6) Social organization and management styles and, finally, 7) Cognitive control of activities, the mental resources and preferences of the actors.

The report gives a description of the concepts used for analysis along these dimensions and, in addition, presents some examples for its application for comparison of field analysis and laboratory experiments.

The paper is a working paper and will be revised and up-dated from the experience gained from further field studies and system design projects.

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Preface

The present taxonomy for cognitive work analysis is a working paper to be discussed and revised as results from further field studies are becoming available. It is mainly intended to serve the following purposes:

1. A contribution to integration and development of cross disciplinary research theories and methodologies for cognitive work analysis in modern, complex work domains. The taxonomy may serve as a common framework, which provides a common language for design of information systems among designers, researchers and groups within cognitive psychology, engineering, sociology, information science, software science etc.

2. A methodology for design and specification of the functionality of integrated, complex, multimedia information systems, which enables designers to predict the kind of behavior of individuals and organizations to be expected in response to changes in work conditions, such as those caused by introduction of new information systems.

3. A methodological tool for planning field studies and data collection in various, actual work domains. It also serves as a means for a consistent analysis of collected empirical data and for representation of the results gained from empirical work studies.

4. A framework for comparison of the features of different work places with respect to behavior shaping features, which can support the generalization of results from particular work studies and enable the designer to be able to transfer results from analysis in one work domain in order to use them to plan and evaluate information systems for other domains. At present results of most field studies are presented in the language of the domain in which case the results are only useful for a particular branch of work. Such a cross-disciplinary framework can further serve to transfer research results between controlled laboratory experiments and complex field studies.

5. A method for evaluation of information systems and the behaviour of individual users and organizations for whom the systems are designed, and for explanatory analysis when discrepancies are observed between design intentions and actual use of the system.

For design of advanced information systems, the key issue is not the design of the individual user-computer interfaces from a cognitive ergonomics point of view but, in stead, the design of a computer based mediator between a number of cooperating actors and their joint work content, it is a cognitive systems engineering issue.

A modern information system is a network of work multi-media stations, designed to present an agent with an information environment which enables the user, within the constraints posed by the work requirements to create actively a work practise that suits the individual users' cognitive resources and subjective preferences. In modern, flexible work conditions, work does not depend on specialized staff members having stable work routines, but on personnel with broad rang of abilities and ability to adapt rapidly to changing work requirements and tools.

In this situation, system design cannot be based on analysis of existing work procedures, but on the creation of an information environment presenting a resource envelope within which the users can improvise and adapt to changing requirements. For such a de-

sign, it is necessary to make available the information necessary in a knowledge base which is structured to match the deep structure of the work domain; to select information necessary for the resource envelope in a particular user's situation, to make it accessible according to the questions a user will ask when following the preferred strategy; and to present the information in complex integrated, formats which match the perceptive adopted during work in the particular domain, i.e., reflecting in a meaningful way the deep structure of the work domain.

At present, such a design is only possible after a lengthy and costly cognitive work analysis in the particular domain. For effective design of future systems, it is mandatory to develop a multi-faceted framework for description of the deep structure of work domains, the work requirements in particular situations, the effective strategies to cope with such situations, the competence and cognitive resources of individuals depending on their education and level of expertise, and the subjective preferences of individuals of different aspiration in work. It is our experience from our own work that such a framework effectively support the transfer of results from work analysis, and design and evaluation of information systems in one domain to analysis and design other, even quite different, domains.

In the future when information systems are no longer separate, local installations, but wide networks of users, special data sources, and general data bases and multi media services. It is our firm belief, that a wider acceptance of such a kind of conceptual framework is necessary for establishing a consistent basis for design of information systems that are effective at the same time as they are accepted by the users. With time, such a framework can support the development of sets of prototypical domain characteristics, work situations, display patterns and metaphors, and user profiles that will facilitate a uniform evolution of complex systems.

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A. THE TAXONOMY

Introduction

Information technology is presently changing human work conditions in several respects. The level of mechanization and automation is steadily increasing, computers are used for planning and control of integrated manufacturing systems, computer based interfaces are inserted in between humans and their work, and advanced communication networks serve to integrate the operation of large-scale distributed systems. In this situation, the ergonomic issue is not primarily the human-computer interaction in a separate tool or 'application,' but the joint influence of technology on work conditions, work organization, and management structures. A new approach to analysis of work is needed together with a new frame of reference for strategical planning and design of socio-technical systems based on advanced technology.

Traditionally, work environments have been planned for efficient production through rather long periods. Products are more or less standardized and change rather slowly, planning criteria are efficiency, economy, and reliability. In this situation, human activity depends on know-how and skills evolving through long stable periods. Quite naturally, therefore, analysis and description of work have been made in terms of 'task analysis' serving to decompose the flow of activity into a sequence of modular elements, 'acts', expressed in terms of the work domain.

In modern work settings, advanced information technology is the origin of many fundamental changes. For example, computer integration of manufacturing systems offers a high degree of flexibility for responding quickly and effectively to specific customer requirements. Therefore, stability and repetitive tasks will be replaced by dynamic environments and concern with flexibility and rapid adaptation to new requirements. Tasks will be discretionary and involve problem solving and decision making and should be analyzed not only in terms of observable actions in the work environment, but also in terms of cognitive processes.

In most work environments, a large variety of opportunities and *action alternatives* are found for all functions of work. In stable work environments, however, only few alternatives are normally considered. Many alternatives for action are neglected due to habits and practice of the individual actor or to company practices and traditions. This fact makes it difficult for organizations to explore adequately the opportunities for restructuring of business when advanced information technology is introduced. New technology means new ways of doing things. It is difficult to identify the potential for restructuring in response to changes in technology when alternative *solutions available* in the existing work setting *are forgotten* during normal operation and *criteria of choice are implicit* in tradition and practices. There is a severe danger that the blindness from tradition and practice will prevent proper exploitation of the potential of improvement actually present.

Alternative ways to approach work requirements which can be important candidates when major changes are made, *can not be identified by observation of the actual work activity*. In order to identify the existing options for change and to adopt new means in the system, an analysis is required of basic *company goals and constraints*, of the

potential relationships among goals, functions, and processes, of the *criteria* available for allocation of roles to individual agents, and of the coordination needed, i.e., the work organization and management structure. In stable, well established systems, the central task is the application and control of certain means for certain tasks, i.e., the usual means-ends relationships are well established and stable. In a flexible, dynamic environment, however, the first and most important requirement in a task is the selection among the available possibilities and alternatives for action, and to determine the most suited one for the goal or function considered, *under the conditions given in the particular situation*. This means that, the most important description is the *possible* means-ends relations between elements of the work domain. The consequence of this situation with respect to methods and frameworks brought into action for analysis and description of modern work conditions is the need for a tight cross-disciplinary cooperation and fertilization and, in turn, a need for a shift towards compatible paradigms in the involved provinces of human sciences. Fortunately, this necessary shift in paradigms is promoted by a concurrent shift in emphasis in several disciplines from behavioristic toward a cognitive point of view, and by the increasing interest in descriptive models of decision making based on field studies in stead of normative models based on theoretical operations research.

The Need for a New Taxonomic Framework

During a period of paradigm shift, however, new concepts, models, and terminology evolve concurrent in several groups. This is presently the case for approaches to the analysis of cooperative work for information system design. We face the need for an improved agreement about concepts, labels, and delimitation of classes of objects of study. For experiments in a laboratory, psychologists are very careful to describe the experimental conditions, and informing the subjects about the goals to pursue. Flaws in such precautions which prevent independent duplication of experiments will make the effort an unscientific enterprise. In real-life field studies, careful instruction of subjects will make the whole study useless; the goal formulation and subjective value structure are key issues of an analysis. Results of field studies, consequently, often are only specified by the name of the system studied, such as 'power plant control room', 'steel rolling mill', and the subjects are identified in terms of their profession such as 'process operators.' Unless, however, the characteristics of the 'process' environment and of the process 'operators' can be explicitly formulated, the danger exist that the results will be judged narrative journalism rather than scientific investigation. The terms 'process operators' implicitly set firm boundaries around the phenomena of interest. It implies that the work environment is bounded by the process system and that the behaviour of the actors supports the design intentions behind the system. If this, except for occasional errors and mistakes, was not the case, they would simply not be 'process operators.' However, if the characteristics behind these labels cannot be explicitly formulated, results will only be useful in the system supplying the data, i.e., for applications like training and work instruction. Generalization for prediction in a different work context, e.g., another system

or in response to introduction of new tools, will not be possible. The data are only valid for an implicitly defined situational context, and consequently, they cannot be accepted as results of scientific inquiry.

The basic problem of the classical task taxonomy seems to be the idea of a simple one-to-one relationship between 'task' and 'behaviour;' the task being the 'cause' and the 'behaviour' the effect. Secondly, the implicit assumption that a taxonomy should serve an exclusive *classification* of a set of complex items for later *identification* of items. In fact, what we are looking for in our efforts to create a conceptual framework for description of tasks, activities, work domains, etc., is a model framework, a framework for *description* which can serve to compare results from analysis made in different contexts and domains, which can serve to *predict* what kind of phenomena are to be expected in one work situation, given results from studies in other environments. Under influence of the present acceptance of mental processes and cognitive phenomena, the basic assumption underlying analysis and description will be one of complex interaction between characteristics of the work requirements, tasks as generated by actors, activities of actors to comply with tasks as perceived, the environment as result of activities, the cognitive processes applied, the criteria governing the individual actor's preferences and the social factors determining the allocation of roles to the individual.

In conclusion: No one exclusive, hierarchical and 'objective' classification scheme will serve to unravel this complexity. What we need is a kind of *teleological taxonomy* (i.e. a pragmatic, goal directed taxonomy useful for the analyst), derived from our need for a framework which can serve prediction of changes in behaviour in response to introduction of new information systems. What we can hope to develop is a theoretical framework for *description*, which can also be useful for *prediction*; a framework which necessarily will have the nature of a multi-dimensional, multi-faceted network of interrelated concepts.

A Law Seeking, Teleological Approach

When developing a taxonomy, also within work psychology, reference is often made to biological classification and taxonomies. It is, however, very important to consider the application one has in mind when defining a taxonomy - which basically is very different for biology and cognitive work studies, except for the common emphasis on the need for a theory and general laws as a basis for the taxonomy. This is discussed below.

Taxonomy in Biology

In short, a taxonomy in biology is the theoretical structure which enables analysts to define exclusive classes, to *classify*, i.e., to allocate specimens to such classes and give them an unambiguous name and to *identify*, i.e., to place a specimen in one and only one class and give it a name. Webster gives this definition: "*Taxonomy, n. [Gr.taxis, order and nomos, a law] 1. The science of classification; the laws and principles covering classification of objects. 2. Classification, especially of animals and plants into phyla, species, etc.*" Webster's second definition clearly shows that in biology, taxonomy is generally defined with reference to the need for exclusive classification of organisms: Taxonomy "is the theoretical study of classification, including its basis, principles, and rules." The use of *laws* as a basis of classification clearly gives a selective focus on the properties which are useful for definition of classes. This approach has been used by Linnaeus as well as by Darwin. Linnaeus based his scheme on the conception that all living species are descendants of those two individuals created by God. Since the species created by God do not mix, they can be identified from analysis of the sexual apparatus. This concept led to the *Linnaean taxonomy* which is the oldest systematic concept. The theory of evolution rapidly was implemented in another 'law based' framework for classification, the *Darwinian or generic taxonomy*. Taxonomists of this school hold that a classificatory group can only be established on the basis of common evolutionary descent or on the basis of homologous characters. In both cases, the taxonomy is based on a theory, and therefore, is very selectively focused. Their validity, however, depend on acceptance of the theory. There are, however, within biology other more pragmatic taxonomies. Linnaeus suggested together with his formal system, another taxonomy for specification of the usefulness of botanical species in cooking. Such taxonomies have been called *teleological taxonomies* referring to usefulness and goals, usually with respect to man as a user of the items which are classified. In a purely teleological taxonomy, there is no need to seek laws which ensure the establishment of exclusive, hierarchical and objective classes.

Task Taxonomies in Psychology

Development of *task taxonomies* has been a topic of interest for a long time. One of the basic difficulties in this effort has probably been the trend to follow the lead of biologists at the same time as a drive to be objective and 'scientific' has been predominant.

Theologus (1969) claims that a theoretical classification should be developed describing tasks in terms of inherent attributes and characteristics of the task which “are the only classificatory vehicles which possess a high content of information concerning the *tasks as tasks*.” -- “Psychology has as yet to develop a theoretical classification of tasks, although Hackman (1968) has suggested a task qua task approach to classification.” This theoretical approach to classifying tasks qua tasks without being influenced by ‘exoteric’ variables related to behaviour can be one of the reasons for the problems with task taxonomies.

A Nomothetic Analysis

It follows from this discussion, that the epistemological approach taken to the development of a conceptual structure, a ‘taxonomy,’ for field studies of human performance depends very much on the fundamental interest of the investigator and of the purpose of the study. This problem is particularly important to consider in a cross-disciplinary exercise involving both humanistic and technical professions as it is the case for any analysis of cooperative work in a modern setting. Engineering professions have a declination towards formulation of general laws and predictive models whereas humanistic and social sciences are more often interested in description and interpretation of particular cases and phenomena. This is, however, not only a question of a technical or a humanistic orientation of research. The question has been widely discussed within professions such as sociology and history. The German philosopher Windelband around the turn of the century introduced the distinction between an *ideographic* and a *nomothetic* approach to historical analysis: The ideographic analysis is close to Habermas’ hermeneutic method which is not focused on identification of general laws but on analysis and interpretation of the individual historical events and scenarios. In contrast, the nomothetic view is most clearly illustrated by the law seeking physical sciences. In effect, the distinction ideographic - nomothetic has been taken to be synonymous to the social - natural science distinction. This is, however, not the case. It is, however, important to realize that lawful behaviour is not synonymous with causal necessity, regularity of behaviour can be brought about by human selection and choice from shared intentions and values. In this case, prediction can be based on assumption about values and related intentions together with capability. Toynbee is very explicit on this point, see the discussion in Rasmussen (1985).

Taxonomy for Work Analysis

The challenge in development of a proper taxonomy in the present context is the need to combine the rigor normally found in engineering analysis with the ability to account for subjective values and preferences and individual differences among people. On one hand, in the context of analysis of cognitive, cooperative work for system design, the purpose of field studies of human behaviour is to uncover *regularities and laws which can serve prediction of responses* to various information technological innovations and, therefore,

a taxonomy must support a nomothetic approach. A useful description for this purpose should represent the functions and processes which must be accepted as elements of work by people in the system. If they do not do so, they are simply not agents of the system. People may act in the system, but if they do not comply with the means and ends found in the system as designed, they will not be considered ‘operators’ but foreigners, i.e., intruders, saboteurs, or terrorists. In Eddington’s terms, this selection of focus of investigation simply defines the features of the net used to catch relevant evidence. On the other hand, the framework must be able to take into consideration that no two agents are equal, that subjective value structures and conceptions of the task requirements lead to different ways of coping with the requirements. What to do may be given by the work context, but how to do it very often is a matter of personal choice. The problem at hand is, thus, to formulate a *conceptual principle* (a theory and law in the same sense as the Darwinian and Linnei taxonomic principles) from which a consistent descriptive framework, a taxonomy, can be developed that will make it possible to *predict* the choices which will be made by the agent in a particular situation.

For our purpose, we need a *nomothetic, teleological taxonomy for field studies based on a theory of systems and their agents as being evolutionary, self-organizing and goal directed*. The establishment of classes in the taxonomy need to be based on *laws of work performance* (as discussed on p. 10-11). Our fundamental assumption is that a human agent within his environment has a large number of *action alternatives*, i.e., to formulate the task, to define the activities, and to control the movements. In order to be able to select a particular sequence of action, a number of explicit or implicit choices and decisions have to be made.

Such a taxonomy is *teleological* in several senses: On the one hand there is the the purpose of the theorist, who lays down the taxonomy, and of the analysts, designers and other clients, who are the intended users of the taxonomy. For both parties the purpose of the framework is to assess the impact of IT designs in work environments. On the other hand, there are the purposes which can be ascribed to the organizations and agents in the work domains under study. The present taxonomy reflects both purposes: Those of the theorists/analysts and those of the agents. Since the taxonomy is determined pragmatically by its usefulness for the analysts, formal rules of exclusiveness, hierarchies etc. have to be substituted by a multi-faceted, multidimensional network.

Objects of the Taxonomy

A closer look is necessary at the requirements for a taxonomy for analysis of cognitive work and design of information systems. It is clear from the discussion in the previous sections, that the taxonomy we need should be based on a theoretical framework describing the interaction between a *work environment* and the behaviour of the *involved agents*. One question remains, however: What are the objects of the classification? Traditionally, the object of classification in work psychology has been tasks, and a taxonomy has been directed to a definition of tasks *as such* (cf. the previous discussion on p. 7). This approach is useful, when considering stable work environments with related professions for which a work practise has evolved with stable work procedures or when considering the normative task sequence which is required for control of well structured technical systems such as technical weapon systems (and complex high risk systems such as power plants and chemical process systems) for which much of the psychological task taxonomy work has been made. For many modern flexible systems, such as manufacturing systems in a highly turbulent and competitive environment, stable work procedures are much less typical.

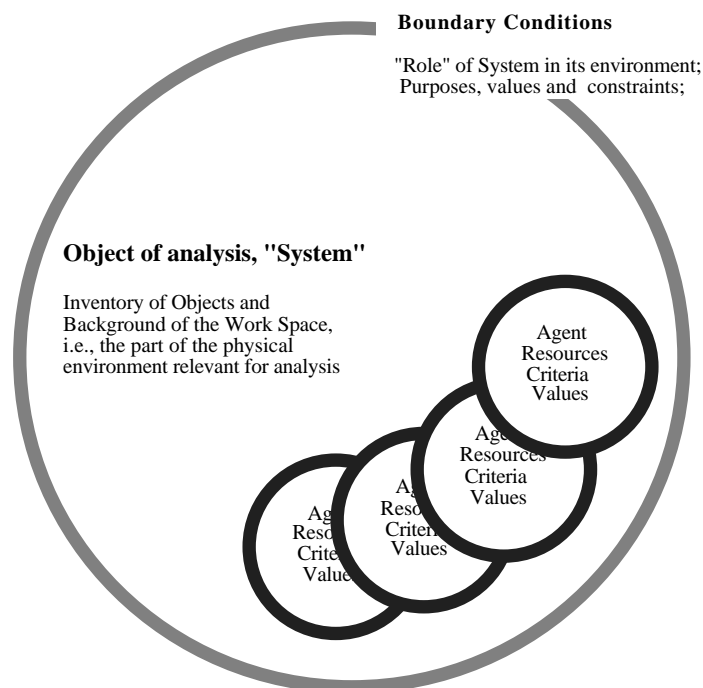


Figure 1. The figure defines the object of analysis of fields studies of work. A part of the environment, i.e., an organization or a company, is chosen for analysis of the activities involved in work performance. This part, the system, is defined by the physical part of the world involved, the functional coupling to its environment, and the agents of whom the activity is to be modelled.

Most of the time, tasks are discretionary, require consideration of goals and constraints and exploration of the boundaries of acceptable performance. In this case, the objects of classification no longer belong to the "task," but relates to features of the work environment and to the interpretation by the actors and the abilities and preferences of the

actors, all of which in interaction create the task ad hoc. The objects of classification, therefore, are the different *work domains* for which information systems are used, and the *individual agents* who are found in the work domains and who will be the users of the systems (see figure 1). To create a systematic, rigorous taxonomy which makes it possible to relate these two classes of objects is no simple matter, and several different dimensions have to be considered. Furthermore, in order to be well focused and to give a rapid convergence of the number of facets to consider during analysis, a well defined *point of view* should be defined.

Basic Points of View of the Framework

The theoretical basis of the taxonomy can be summarized in three fundamental principles:

1. Evolutionary Systems

The basic point of view taken is to consider work and work organization in a dynamic environment to be a *self-organizing* and *adaptive* system or organism. The system is adaptive in the sense that it will change properties to maintain match with needs when its internal conditions and/or the environment change. Adaptation is a kind of *goal following* behaviour. Performance is changed to keep some measure related to performance criteria of the system at an optimum. But adaptation is not controlled entirely by a governing function or agent within or without the system. *Control of adaptation* is distributed across all individuals, teams and organizations. In other words, a distributed, self-organizing feature will shape the functional structure of the system, the role allocation to people, and the performance of the individuals. To be useful for analysis of work and for prediction of responses to changes of work conditions, the taxonomy must reflect the mechanisms underlying *the evolution of work practice*. Adaptation is evolutionary, it is not planned by anybody by rational analysis. The properties, i.e. the structure and performance of the system, emerges from the “survival of the fittest “ of the structures and performance. This happens to a large degree as a result of trial and error experiments, planned and unplanned, conscious and unconscious.

This point of view has a number of immediate implications:

2. Goal Directed Systems

The systems we study are *goal directed*, *they have to serve purposes in an environment in order to survive*. The socio-technical system exists because the system and the environment shares certain goals, which, by recursion, is the case both for the entire system and for any sub-set in terms of teams and individuals. Systems for which information technology is particularly influential exist in dynamic, turbulent environments, their goals change, requirements and opportunities in the environment change, and the means and tools to pursue goals and adapt to changes vary. In this situation, a taxonomy must reflect this exploration and adaptation by the agents to the work environment.

3. Action Alternatives

Evolution and Constraints. Great diversity of behavioural patterns is found among the members of an organization. No two individuals are occupied by the same activity, no two patterns of movements are equal. The variety of options with respect to ‘what to do when and how’ is immense. In order to predict why a particular individual is present in the organization at all, and why a particular piece of behaviour is chosen instead of one of

all the other possible patterns, we have to understand how all the *action alternatives* in a particular situation is eliminated such that one unique sequence of behaviour can manifest itself. As long as more action alternatives remain, behaviour is indeterminate until a choice is made.

To identify the kind of behaviour to expect among all the possible options for action, we have to identify the *constraints* which shape behaviour by guiding the choices taken by the individual. A problem in identifying behaviour shaping constraints is that *they will not all be active at the time of the behaviour* they control. Behaviour has a prehistory. Patterns of behaviour evolve, they are shaped by prior decisions and choices. When a piece of behaviour is planned by situation and goal analysis and consideration of alternative options for action, the behaviour shaping constraints are being compiled into cue-action patterns and will not be active in later situations, when the particular pattern of behaviour is re-used. It is, however, necessary to identify these 'hidden' constraints in order to predict and understand behaviour, even if they are no more needed for control of behaviour. This identification can be difficult, because often they are no more known by the actors and therefore have to be inferred from the work requirements, the resource profile of the actor, and their subjective performance criteria. See figure 2.

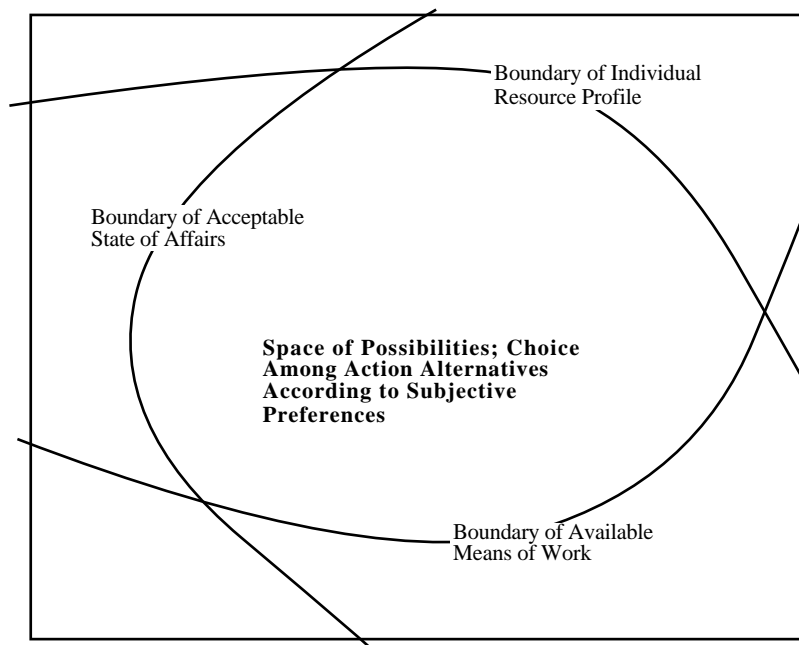


Figure 2. Human behavior is governed by constraints which must be respected by the actors for the work performance to be successful. Identification of such constraints will specify the 'space' in which the human can navigate freely. Violation of the constraints will be considered human error or task violation in the usual sense. One boundary is given by the control requirements posed by the system. Another constraining boundary is given by the human resource profile, which depends on individual characteristics such as competence, mental capacity, physical strength, etc. Finally, navigation within the envelope specified by these boundaries will depend on subjective criteria for choice, such as aim to save time, to spare memory load, to have fun, to explore new land, etc.

Myths - Doing and Understanding

In this way, knowledge about goals, constraints, and internal functional properties of the work environment is only necessary for initial planning of an activity, for exploration of the boundaries of acceptable performance in new territory, not for control of behaviour during repeated encounters of the same situation.

In stable work environments, know-how and established work practice are normally learned by novices from the older staff members, and optimized empirically in a trial-and-error mode. In this situation, the basic understanding of goal structures and internal functionality will tend to deteriorate. Some kind of such declarative knowledge, however, is still useful for rationalization and explanation of the need for activities. Therefore, and a kind of ‘operator logic’ or myths about goals and reasons can evolve and replace the knowledge actually underlying system rationale. Such an informal, mythical knowledge-base will not be reliable when disturbances or changes require analytical, knowledge-based planning. Therefore, to base decision support systems on such ‘operator logic’ will be a mistake. Furthermore, mythical operator logic will not be a reliable source of information about the work domain, such a representation must be based on analysis of the actual functionality of the domain. For this, a formulation of the intentions and reasons behind work domain structure is necessary and inferences from field studies are necessary. For decision support, ways to bring this knowledge-base of the work domain to the agents’ disposal should be found, if they are supposed to improvise during disturbances and changing work conditions.

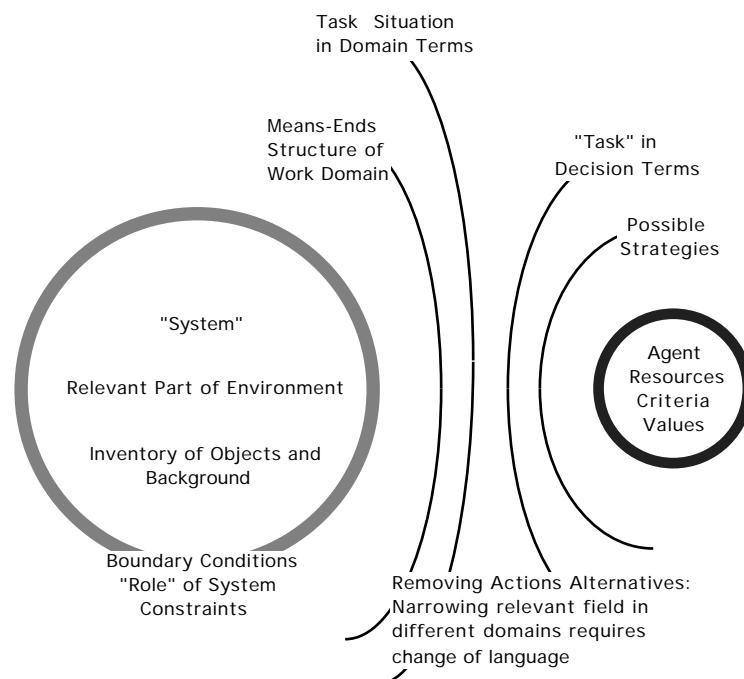


Figure 3 illustrates the problem faced when developing a taxonomy for predictive models of behaviour in a complex work context. Several layers of representation in different languages are necessary in order to be able to relate cognitive and emotional characteristics of a particular agent to the characteristics of a work environment.

Two Starting Points of Analysis

A taxonomy intended to support work analysis aiming at strategical planning of advanced information systems and the involved prediction of the influence of such systems on work performance and organization, clearly have to take off from two different starting points:

- 1) a representation of a socio-technical system and its interaction with the surrounding dynamic society,
- 2) the subjective human interpretation of the state of affairs in the world and of the action alternatives of the agent.

Therefore, the taxonomy must accommodate several shifts of language of representation to interrelate concepts from a number of professions. See figure 3.

Different Dimensions of the Taxonomy

The aim is, as mentioned, to find a conceptual framework for strategic planning of integrated information systems including advanced human-machine interfaces in high-tech systems. The framework is, therefore, intended to be pragmatic and rigorous. Even if rigor to the degree that a computational verification at present is only possible in principle, it is taken to be the target guiding the overall strategy of research. At the same time, the model and taxonomy must reflect the subjective interpretation of the work environment by the agents involved. To comply with this requirement, the representation of the work domain is based on interdisciplinary and ethnological studies of the actual work environment, not on normative formulations of work requirements. In this way, the approach is intended to combine several sciences spanning from engineering to the basic human sciences. Concepts from these sciences are needed to formulate several levels of analysis bridging from the technical description of work domains to the subjective values of agents, as illustrates in figure 4 and described in more detail in figure 5 & 6.

From the discussion in the preceding sections, it is concluded that a framework for our purpose must include the features of work environment and agents which determine the evolution of work practice, whether this is guided by the designers' methods during system conception and formal instruction of the staff and/or the actual performance is guided by empirical trial and error through time. Only if the basic constraints shaping this evolution is represented, a taxonomy and model will be able to support prediction of responses to changes in work conditions.

Figure 5 illustrates two concurrent analysis of work and work performance. One serves the identification of the activities which an agent is faced with, another serves to identify the role and characteristics of the individual agent - as described below in more detail. In addition, the mutual relationships between these two dimensions of analysis should be kept in mind, hence the need for concurrency.

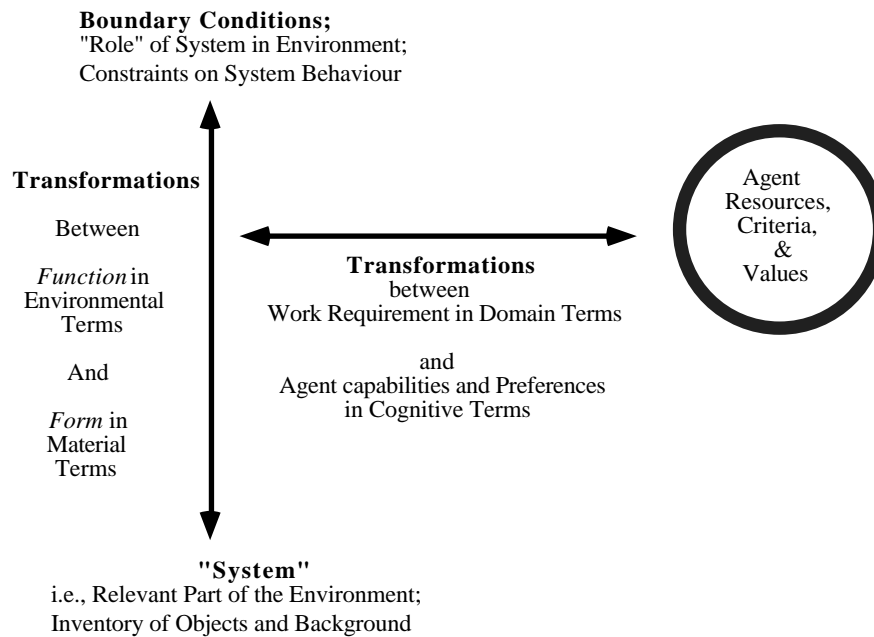


Figure 4. The structure of the taxonomy. The taxonomy clearly take off from two different points of view: a representation of a sub-set of the material physical world and its interaction with a dynamic environment, and the subjective human interpretation of the state of affairs in the world and the options for action. Therefore, the taxonomy must accommodate several shifts of language of representation to interrelate concepts from a number of professions.

Dimension 1. Identification of Activities

This is concerned with the ‘work requirement,’ which will be compared to the agent’s resources and preferences in order to determine the individual choice of performance. It is important to stress that this analysis will not be a normative prescription, but should be based on an ethnologic analysis of actual performance. It includes implicitly, by the selection and formulation of task and strategies, the subjective formulation by agents of their actual goal, the way they view their task, and their possible ‘cognitive styles.’ This is done by including the repertoire of ‘*possible*’ formulations of tasks and strategies which, judged from the field studies, are relevant, i.e., *can be used* by an agent dependent on the subjective interpretations. This analysis is based on interdisciplinary studies such as a classical operations research, certain ethnographic studies etc..

Dimension 2. Identification of the Agent

The other line of analysis is aimed at a description of the role, the resource profile, and the subjective preferences of the individual agent and of the cooperative structure. This analysis involves the description of the evolution of the actual (informal) cooperative structures and work organizations. The organization here will be considered an open,

self-organizing organism, in accordance with the management and organization theories represented by Thompson, Weick, and the Berkeley group.

Dimension 3. The Interaction

The interaction between the two lines of analysis is complex and iterative. *Task allocation* interacts with the description of the structure of the work domain and the nature of the task situation. The description of the mental strategies which can be used must be compatible with the description of the individual's resources and preferences. Finally, when a match between possible strategies and preferences has identified the chosen strategy, it has to be 'folded back' onto the higher levels of analysis and the work domain in order to determine the actual behavioral sequence.

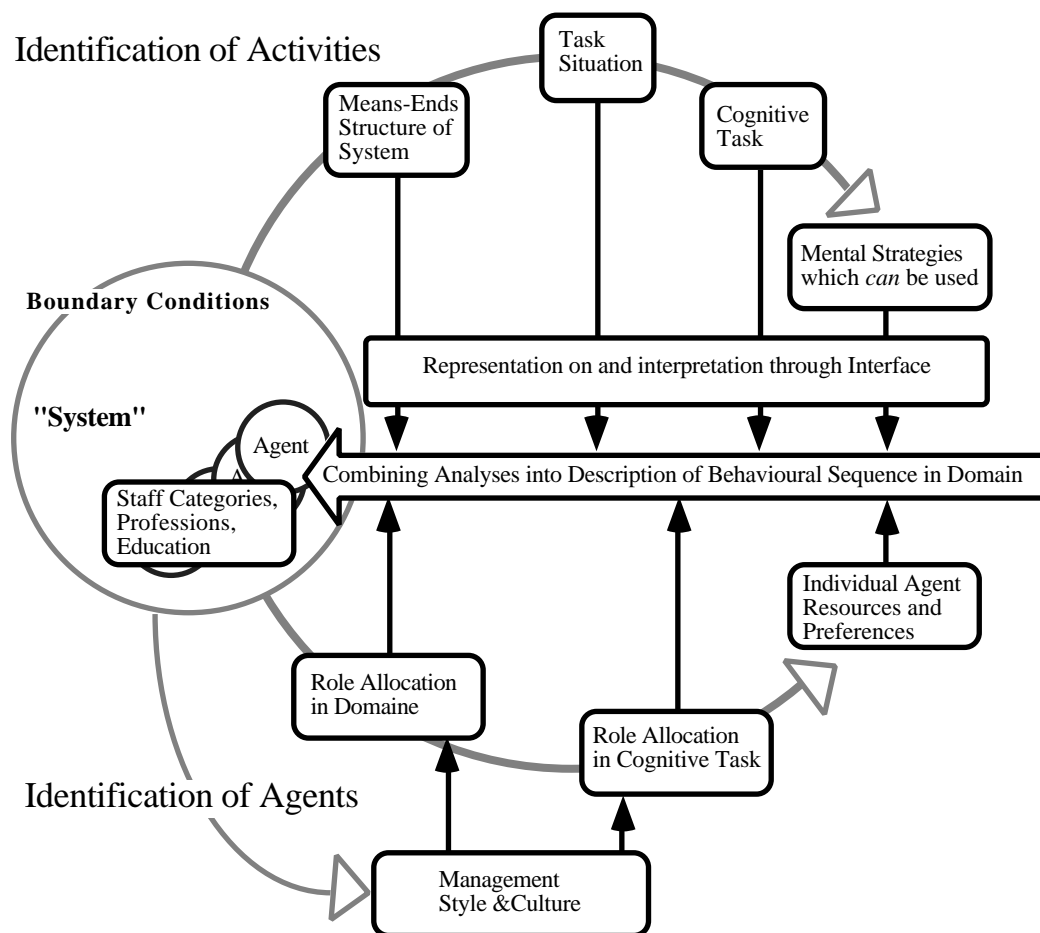


Figure 5. An overview of the taxonomic framework. The behavioural trajectory unfolds from the interaction of the task requirements, as identified by the upper analytical sequence, and the individual agents role and resource profile, as identified by the lower sequence. The role of the interface transformation is sketched to indicate that behaviour can be effectively controlled by the choice of interface representation. The *content* of interface communication is given by the task and the agent resources, The *form* of the presentation, however, can be chosen independently to match that performance criterion which activates a strategy consider most effective by the designer.

The Analyst's Strategy for Description

To find a useful framework, it will be necessary to adopt an economic strategy of description, i.e., to select an approach which leads to a *rapid convergence* in the elimination of the action alternatives left (to and by) the agent for choice. A conceptual structure is needed like the top-down partition strategy used in the game of 'twenty questions.' The first level of the 'twenty questions' leading to the descriptive strategy, therefore, will be to prepare the stage of human action by explicitly defining the goals and constraints posed by the environment which in general must be respected to be accepted as an agent within the study, together with the means for action which are available to an agent. In the present problem, this implies a description progressing top-down from the general aspects of the part of the world to consider, i.e., the boundary of the system in question, to the particular aspects related to the preferences of the individual agent.

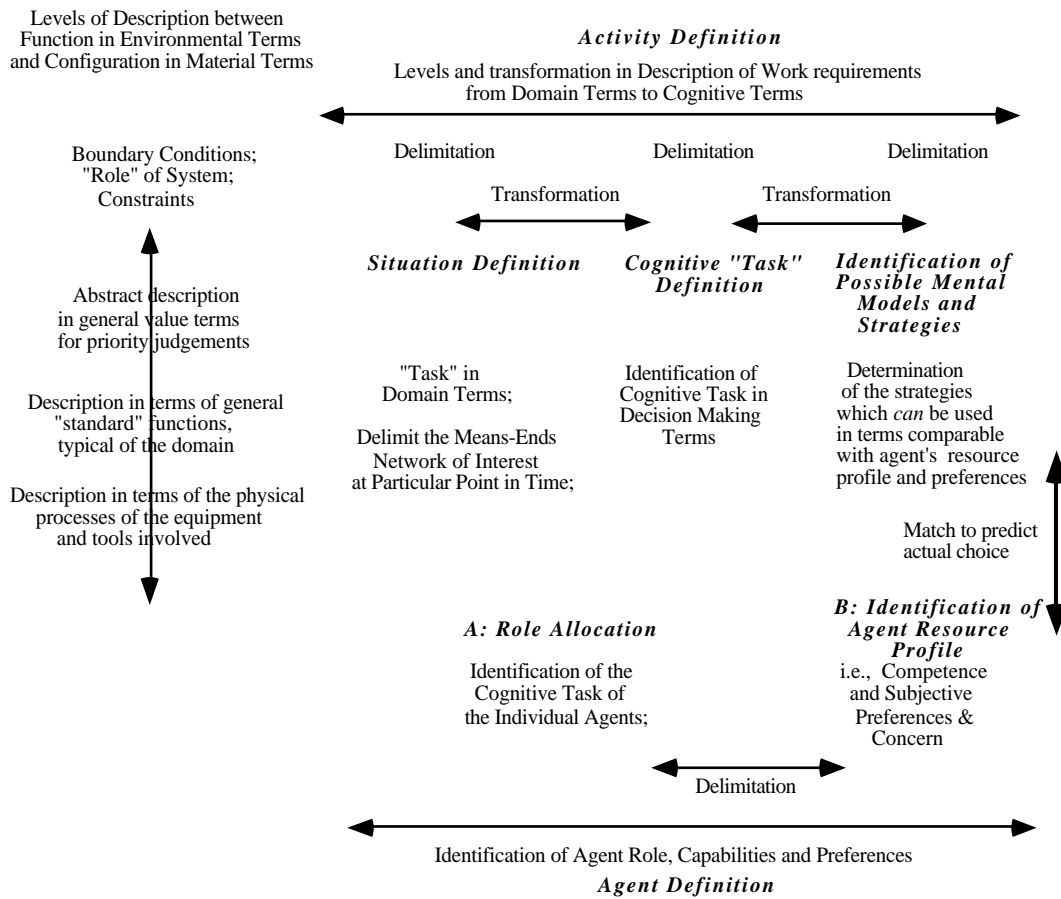


Figure 6. The figure gives an overview of the entire system of transformations and delimitations necessary to be able to relate the definition of the work space to the cognitive resources and subjective preferences of an individual agent.

The constraints, i.e., the boundaries around acceptable and preferred action sequences depend on the ends and means inventory of the work domain in question, on the requirements in a particular situation, on the physical and mental resources of the actors involved, and on their subjective goals and criteria. It is shown in figure 6, how the frame-

work should be able to support a *step-wise narrowing down* of the action possibilities considered by an agent (i.e., of the alternative possible ways to meet work requirements, of the options among which a choice must be made). In addition, *shifts in language of description* will be necessary according to the basic source of the constraints, going from the context of the work domain, the situation calling for human intervention, the structure of the related control domain, onto human cognitive and emotional factors.

Choice of Terminology

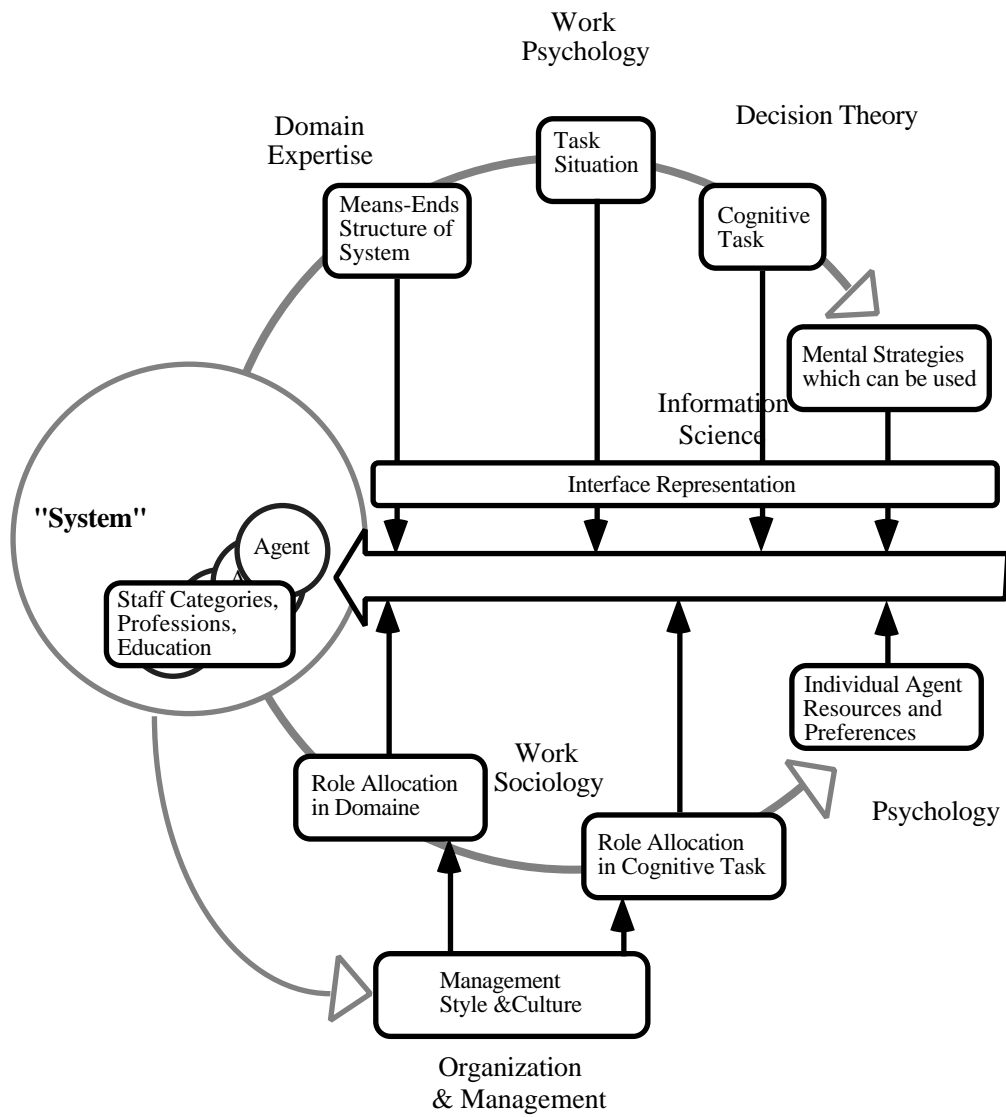
In the previous sections, a taxonomy is described which has been developed from field studies in several different work domains. It represents a conceptual framework which has emerged gradually and organically from the needs which have been met for analysis and description of cooperative work. The framework includes a multi-faceted description based on a theory and laws for categorization within each of the dimensions or facets of description. This, in fact, implies that the relevant set of categories and the related terminology should be established for each dimension or facet.

Classes and Terms, Derived or Imported?

To be useful, a cross disciplinary framework must serve to bridge, as far as possible, the terminology established within the professions involved. The most productive solution will be to import, whenever possible, the classes and terminology from the “school” closest to the present context, i.e., which is compatible with the self-organizing, adaptive systems view.

Figure 7 illustrates how different more or less established professional domains are involved within which it is important to explore and, as far as possible, to apply the established concepts and terminology.

In some cases this can be difficult due to the present paradigm shifts. This is the case in e.g., decision theory (models of ‘naturalistic decision making’ is presently attacking the normative analytical school) and cognitive science (where different schools based on psychology and computer science compete).



B. THE CLASSIFICATION

Introduction

In the following sections, a taxonomy is described which has been developed from field studies in several different work domains. It represents a conceptual framework which has emerged gradually and organically from the needs which have been met for analysis and description of cooperative work. The taxonomy as presented in the previous section is kind of a rationalization after the fact and an attempt to formulate why the framework has been found to meet the requirements during the field work. The framework includes a multi-facet description with a taxonomy for categorization within each of the dimensions or facets of description. This, in fact, implies that the relevant set of categories and the related terminology should be established for each dimension or facet. In the following sections a review is given of this framework. It is offered as an example for discussion and further development. The review includes the following elements:

- *Definition, delimitation, and decomposition* of a work system
- *Classes and terminology* for *description* of a work system
- *Methods* for *analysis* of a work system
- *Application* of description/analysis in design of information systems
- *Discussion* of literature on the description of work systems

The classification, i.e., the level of decomposition of the description and the elements to include will vary according the purpose of the analysis and can, in principle, only be defined iteratively during the analysis. It is, however, not possible to enter a complete and detailed work analysis from scratch in every case, and some heuristically defined aspects to include are important to guide the analyses. The importance of the present taxonomy, therefore, is to supply a framework for recording and communication of relationships, classes, and terminology which have been found useful.

We have, within the MOHAWC project, to discuss the terms we are using and to agree on some of the basic distinctions. It may not be possible, in general, to agree on a terminology at present, but at least we need a mapping between some of the key distinctions.

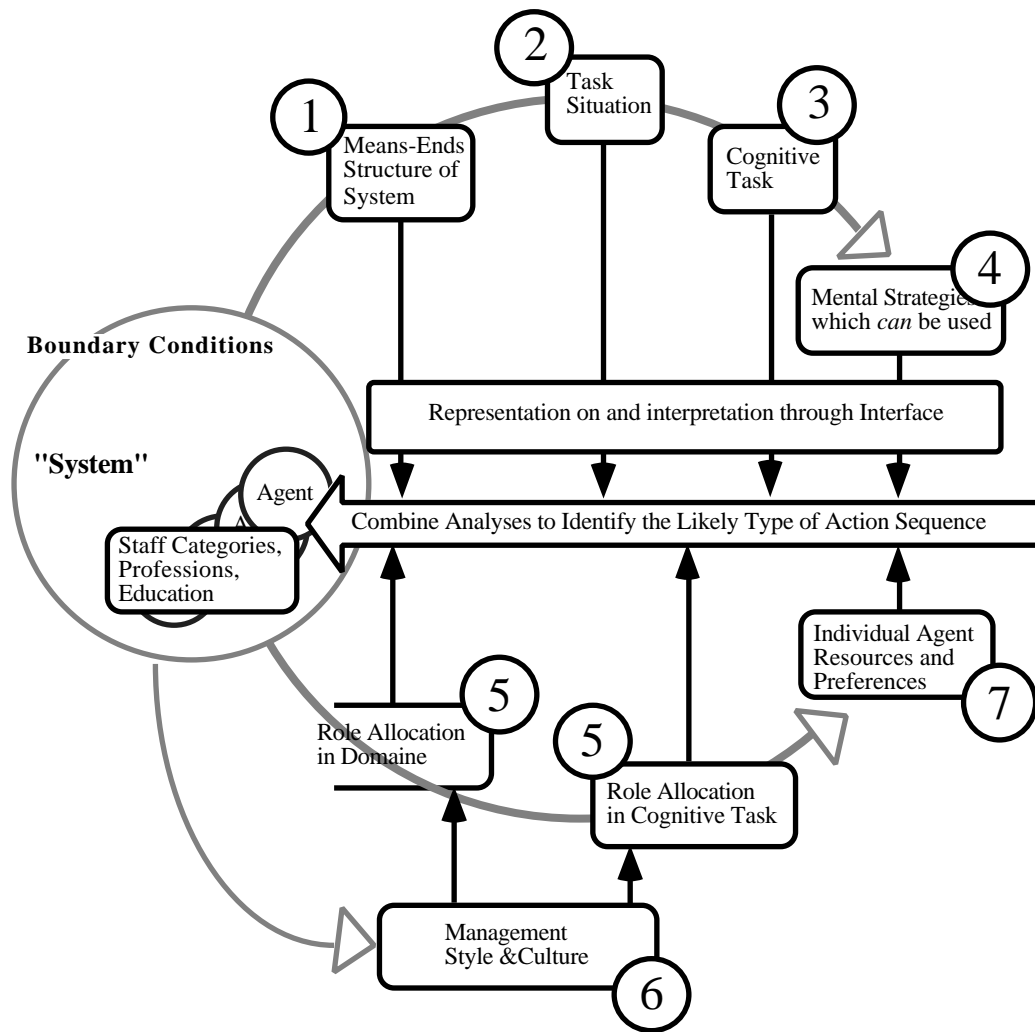


Figure 8 An overview of the taxonomic framework. The numbers indicate the different dimensions of analysis discussed in table 9 and the the following sections

Table 9. Seven Points of View in Work Analysis

1. **Work Domain, Task Space** (Situation Independent Representation).
Means-ends/whole-part map of landscape of work.
Defines the inventory of potential means-ends relations.
Focuses attention on implicit values, goals, and constraints.
 2. **Activity Analysis in Domain Terms** (Categorical, not procedural).
Identifies prototypical work situations and tasks in domain terms.
 3. **Decision Analysis in Information Terms**
Identifies cognitive decision functions in information processing terms.
 4. **Information Processing Strategies** (Navigation in Work Space).
Identifies possible, effective strategies which *can* be used for decision functions together with the related resource requirements.
 5. **Allocation of Decision Roles** (Work Organization).
Defines agent roles in terms of work domain and cognitive task allocation.
Identifies the *content* of communication necessary for coordination.
 6. **Management Structure** (Social Organization).
Identifies the *form* of coordinating communication. Defines management structure with reference to social values and conventions for social interaction.
 7. **Mental Resources, Competency, and Preferences of the Individual Actor.** (Novices/Experts).
Relates mental models with levels of expertise and agent resources. Identifies performance criteria; which strategy *will* be used?
-

Definition of System

The first delimitation of a description will be to define the system of interest within the total environment. Identification of the system in the general environment requires two levels of description, one to identify the constituents of the system, another one to identify the coupling to the environment. The objective of work analysis is to improve a situation in some way, by designing and implementing information systems, by redesigning the work organization, by recommending a retraining program, etc.

In other words, the overriding perspective is reformist or therapeutical: the work analyst investigates so as to change the given system of work for the better. Thus, the analysis cannot take the current behavior of the system of work for granted. To the contrary, the analyst has to 'take it apart', that is, the analyst must uncover the hidden rationale of the current practice as well as the accidental choices of the past, the procedures turned rituals, the formalized mistakes: What is necessary so as to meet current and future requirements of the work environment? What could be done differently, and better? What should be discarded as mere relics? In a sense, then, work analysis can be likened with 'reverse engineering' in the sense that the analyst approaches the given system as a result of a design process, then takes it apart so as to put it together again, perhaps differently. The analyst investigates the system to learn what it does and how and to decide what could be done differently. In a similar sense, work analysis can be compared to psychoanalysis in that it seeks to uncover the 'unconscious' mechanisms of the system of work so as to enable the system of work to overcome fixed patterns of behavior. Thus, in a discussion of the methodology of organizational studies, Selznick (1957) argues that rather than following the lead of experimental psychologists who study routine psychological processes, the analyst should imitate the clinical psychologist who examines the dynamic adaptation of the organism over time. Thus, instead of focusing on the day-to-day decisions made in organizations, Selznick recommends the analyst to concentrate on those critical decisions that, once made, result in a change in the structure itself. That is, the fundamental approach of work analysis is to question the rationality of current patterns of behavior. The crucial question is not *how*, but *why*.

Delimitation of the System of Work

Work analysis is always confronted with a particular object, a particular entity in the realm of work at large. Thus the first delimitation required in an analysis will be to define the particular object of interest and thereby define the boundary between the *focus system* and its environment. This initial system definition has two dimensions. First, the focus system itself, *the system of work*, is a socio-technical system, i.e. an ensemble of cooperating agents performing a purposive transformation by means of a complex of technical resources (tools, machinery, equipment, installations, etc.). Second, the analysis should define the *work environment*, that is, identify the part of the world that is being serviced by the system of work, and define the set of requirements posed by the work envi-

ronment to the system of work. At this initial stage an informal definition in the following format may suffice:

Agent: Who is doing it? E.g., a particular company, a division of a corporation, a network of companies, a department of a company, a network of agents in a company, a government agency, an institute.

Work domain: What is being done? E.g., medical care, car manufacturing, engineering design, power production, public administration, investment counselling, mathematical research.

Objectives and Constraints. E.g., demands on product quality, product life cycle, lead time, process security.

Technical resources: By means of what is it being done?

Customer: Who is being serviced? E.g., a market, a company, a clientele.

The initial delimitation of the system of work should express, succinctly and in general, domain-specific terms, the determining characteristics of the focus system, its inventories and boundaries, and its interaction with its environment. These two aspects are discussed in more detail below.

System Inventory and Boundaries

This is an overview of the part of the material world which is included in the system of interest. i.e., an inventory of the material objects and their topography included in the system, a list identifying the individual people acting in the system, the work premises, tools, equipment, etc. For a power plant this includes specification of process system by type and name, configuration, location; buildings by configuration and location, drawings, architecture; work shops with equipment; record of the individual members of staff, names, personal data, profession, etc. For a hospital, the record includes buildings, layouts, architecture, special facilities as patient rooms, operation theaters, laboratories, etc.; identification of all staff members, profession, names, personal data; same for actual patients present. In short, this is the physical arena in which actors navigate, find things and people. It supplies the map of the location of people and things. It represents the physical world you can inspect visually by a visit to the site.

Interaction of System with the Environment

Additional delimitation is supplied by a representation of the coupling to the environments in terms of the goals to pursue and the constraints which are posed by the environment and which should be respected within the aim of the analysis. This identification of the purposes and constraints of the system identifies the values and intentions driving activities of the system.

In case of a *hospital*, examples to be mentioned are purposes such as curing patients, doing research to improve treatment, teaching of students and new candidates, creating an acceptable environment for patients, supplying board and lodging, responding to public opinion on treatment priorities, offering good working environments for employees, etc.,

and to do this as economical as possible within the funding supplied by society and sponsors. In addition, a number of constraints are posed by the environment such as legal and regulatory rules: worker protection regulations, financial rules, union agreements, etc. In case of a *power plant*, the purpose of course is to supply power to meet the costumers' immediate requirements, but at a competitive price with acceptable return on investment. This latter requirement can lead to side goals as to develop district heating, to build greenhouses, or to breed salmon from the energy losses involved in the thermodynamical cycle. In addition, safety regulations and legislation regarding pollution must be met. Finally, the goals and constraints related to the general staff care are considered as it was the case for hospitals.

1. Work Domain Description: Its Means-Ends Configuration

The first facet of the model framework is concerned with a representation of the work domain. *Work* is taken to be “general activity in a defined setting, called the *work domain*, having the explicit or implicit intention of meeting some established needs or purposes.” A representation of the work domain must identify the entire network of means-ends relations relevant for the system considered, i.e., the world of ‘possibilities,’ the requisite variety which is necessary to cope with all the requirements and situations the system might face. The representation defines the landscape through which the agents or actors of the system will navigate during their work. The work domain representation should be a map, identifying all the items of work, defining the necessary background information and, thereby, give structure to the ‘resident knowledge-base’ for the entire system. From this knowledge-base, the necessary working knowledge can then be selected and activated in working memory for coping with a particular situation.

The Map of the Domain

For the control of any work activity, it is necessary to *select the item of work* and to plan the appropriate actions, i.e., to select among available resources, those relevant for the actual goal, and to control the use of the item chosen. Whether this involves a decision task or is mere routine, depends on the particular situation and agent. If however, there should be any decision task, there will have to be alternatives for choice of action, and the representation of the work domain should display the available resources for various functions and goals in a situation independent way.

Manipulation of the work space basically implies selection of available means for the actual ends, considering the goals and constraints of the task. A representation of the work space in terms of a map within which to navigate can in one dimension be defined by *means-ends relations*. Another important dimension reflects the span of attention of a decision maker in terms of *part-whole relations*, i.e., how much of the work space that is actually considered. A change in representation along both dimensions is typically used to cope with the complexity of any unfamiliar work situation (Rasmussen, 1986).

Information from different levels in the means-ends dimension is important in discretionary decision making tasks. The lowest level of abstraction represents the physical form of the system, its material configuration. The next higher level represents the physical processes or functions of the various components and systems in a language related to their specific electrical, chemical, or mechanical properties. At the next higher level, the functional properties are represented in more general concepts without reference to the physical process or equipment by which the functions are implemented, and so forth, up through the hierarchy. At the lower levels, elements in the process description match the component configuration of the physical implementation. When moving from one level of abstraction to the next higher level, the change in system properties represented is not

merely removal of details of information on the physical or material properties. More fundamentally, information is added on higher-level principles governing the co function of the various functions or elements at the lower level. In man-made systems, these higher-level principles are naturally derived from the purpose of the system, i.e., from the reasons for the configurations at the level considered.

A change of level of abstraction involves a shift in concepts and structure for representation as well as a change in the information suitable to characterize the state of the function or operation at the various levels of abstraction (see figure 10). It is important to realize that the different levels are representing information about the same physical world but the information chosen for representation is selected and transformed so as to facilitate the identification of the decision and coordination task at that level between the physical state of affairs and the ultimate human purposes and constraints which is most suited to the actual situation. Therefore, the levels are not given by laws of nature, but depend on human conventions for system representation (Rasmussen, 1979, 1986).

In other words, models at low levels of abstraction are related to a specific physical world which can serve several purposes. Models at higher levels of abstraction are closely related to a specific purpose which can be met by several physical arrangements. Therefore shifts in the level of abstraction can be used to change the direction of paths, suitable for transfer of knowledge from previous cases and problems, e.g., by analogical reasoning (Rasmussen, 1985, 1986).

For effective support of decision processes, therefore, the substance matter of a work domain should be represented at several levels of abstraction, representing goals and requirements, general functions, physical processes and activities, as well as material resources. Decisions by human agents are only required because of the many-to-many mapping between these levels. In any work domain there are many degrees of freedom in the means-ends network which have to be eliminated by human choice, guided by functional (product) criteria as well as subjective (process) criteria. Any work function (*what* should be used) can be seen both as a goal (*why* it is relevant) for a function at a lower level, and as a means for a function at a higher level (*how* this is realized). This, in turn, leads to the requirement that in order to be able to make a proper choice, information concerning the work domain should be accessible in a knowledge base from several different points of view, i.e., by different formulations of the search questions.

The means-ends representation primarily serve to structure the entire, complex many-to-many mapping between purposes and constraints imposed on a system and the material resources available in the system (including people, see the example drawn for a hospital system in figure 13 and for manufacturing in figure 14). It represents the entire repertoire of elements, i.e., functions, processes, people and equipment, from which the relevant subset has to be drawn for a particular situation. In other words, it maps the field in which a decision maker or worker has to navigate in order to comply with work requirements. In essence, this means that means-ends exploration of options involves finding the means for the function required at the same time as the implications for other functions (possible side effects) are considered.

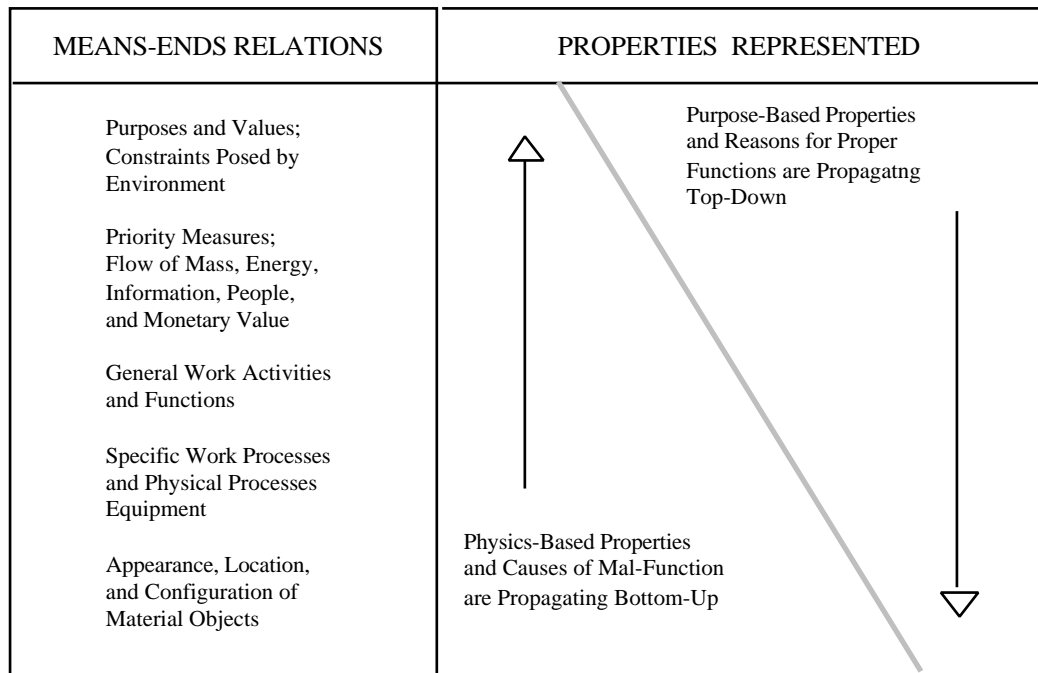


Figure 10. Any system can be described at several levels of abstraction. When moving from one level to the next higher level, the change in system properties represented is not merely removal of details of information on the physical or material properties. More fundamentally, information is added on higher-level principles governing the co-function of the various elements at the lower level. In man-made systems these higher-level principles are naturally derived from the purpose of the system, i.e., from the reasons for the configurations at the level considered.

Definition of the Means-Ends Levels

The subsequent reasoning about the element in the work domain depends on an analysis of suitable representations of the constraints which actually determine the possible relationships among observations of state-variables related to the items of the domains. It is, in fact, the different categories of constraint representation that defines the different levels of abstraction in the means-ends hierarchy, see figure 11.

The level of *physical form* represents the physical location and appearance of the material world. In work, this level of representation is necessary to identify objects from appearance, shape, color, size, and to find them in the material landscape. In any form of work interface, this level is necessary to find one's way, and to direct attention to objects which are potential sources of information, or which are objects to act upon. The template for search in the material world, however, will typically not be defined at this level, unless one is looking for a particular, individual object. In general, the template is defined from the higher functional level, e.g., looking for a cup, one is normally looking for something useful for drinking, not an object of a particular shape or color; unless looking for the jug, bought in Mannheim.

At the *physical process* level, the representation is focused on the physical process which is in action in particular material components. A particular material configuration defines the boundary conditions for the interplay of laws of nature in a way, that result in

a behavior which can serve higher level functions. A centrifugal pump is configured in a way that the spinning of the impeller together with the inertia of a fluid and the centrifugal forces result in a flow of a fluid. To accomplish this, bearings are necessary with a material configuration such that the surface tension and viscosity of oil prevent that metal surfaces get into contact when revolving. Alternative options are available: in piston pumps, the material configuration of the pump is chosen so as to let movement of one part within the cavity of another result in displacement of an incompressible fluid. For control of the particular component, it is necessary to consider its nature at this level. Control requirements of pumps based on different principles will be different, but their role in the total system function depends only on input-out-put characteristics, i.e., on a black box representation.

MEANS-ENDS RELATIONS	PROPERTIES OF THE SYSTEM SELECTED FOR REPRESENTATION
Goals and Purposes, Constraints.	Customer and market relations; competitors; production volume requirements; legal requirements for financial relations and environmental protection; work safety legislation; workers' union agreements;
Priority Measures; Flow and Accumulation of Mass, Energy, Information, People, and Money.	Topology of Flow of Products, Energy, and Various forms of Material, (Losses, Contaminants, Raw Material, etc.); Sources and Sinks of Funds; Flow through the System of Monetary Values; Man Power Turnover.
General Functions and Activities.	Marketing, Personnel Administration, Design, Production Planning, Production, Maintenance; Casting, Cooling, Heating, Purification, Material Conversion, etc.
Physical Processes in Work and Equipment.	Work Activities and Processes; Physical, Technical Characteristics and Processes of Equipment, Machinery, Tools, and Components; Capabilities and Limitations; Control Characteristics;
Appearance, Location, and Configuration of Material Objects.	Material Characteristics, Shape, Size, Weight, Appearance, Location; Anatomy and Configuration of Equipment and Installations; Building Layout; drawings; Access Roads and Site Topography.

Figure 11. Several different representation languages are necessary to connect the identification of the physical system to the environmental requirements in terms of the processes of work activities and equipment serving the various functions which are needed to meet the goals. The figure, in a way, represents the *control structure* of the work domain.

This is represented at the level of *generalized function*. At this level of representing the function of a pump in a system, its internal properties do not count, and pumps of different physical principles will all be member of the set 'pumps' in which distinctions are related to capacity, acceptable pressure head, power consumption, etc., because their role in the system is to circulate fluid. The point here is that different particular objects, possibly based on different physical processes can serve the same function, there is a many-to-one mapping, giving degrees of freedom and thus a basis for choice; in design among different possible solutions, in control among different physical objects of intervention.

The necessity for this generalization comes from the need to coordinate the functional implications in a system independent of the underlying physics in order to save mental effort and to be able to replace the physical component underlying a function: if you have

no more cooling pumps available, circulation may be established by a fire-hydrant, and this option should be offered by the representation of the work domain accessible to an actor. Given different options, other criteria than immediate function at a higher level are necessary for choice. This depends on different influence of the choice on other higher level features. Different choice of pumps will influence the availability of pumps for other functions, different pumps may have different maintenance characteristics, or different power consumption, or different influence on work climate, such as noise. In effect, this means a one-to-many mapping upwards through the levels. Ultimately, the implication is that the means-ends map reflect a complex many-to-many mapping of mutual interactions.

At the *abstract function* level, representations are found which are useful to coordinate across functions. This task requires representations in terms of concepts which are independent of the particular domain as well as its environment. In order to be so, it has to be based on very basic principles, such as conservation of mass and energy (by laws of nature) or of monetary values and number of people (by human conventions: you do not kill people or burn money), or on information-theoretic measures such as truth, information content, etc. Incorporated in such measures can be grades expressed in terms of probabilities, risk, etc., the basic point being that the measures of flow of such magnitudes in the system will enable the measurement of match in the mappings of system specific functions onto environment specific requirements.

The highest level of *goals, purposes and constraints* represents the ‘functional meaning’ of the entire system in terms referring to properties and functions of the environment. Here market relations, competitors, and value structures referring to the goals of the system, its departments and groups as well as the individual staff members are found. In addition, constraints posed by laws and regulations concerning financial aspects, employee work conditions, union relations, environmental protection, etc. at the general level are included.

Analysis

Such an overview of the work space, therefore, should be developed from information collected by general, unstructured interviews of actors at all levels of an organization. The interviewed person should be involved in description of his general activities, “what is done” e.g., through a day, in characteristic situations, etc. In addition, the levels of the domain should be explored by means of questions, “why” certain activities are relevant, and “how” they *can* be done, i.e., alternative means should be identified if available. Before such interviews take place, the analyst should prepare a rough sketch from his general knowledge, from news paper discussion about the special branch of business which will serve to focus discussions of present goals and constraints, from technical books to have a vocabulary of the instrumental part of the space. The description will be supplemented by information collected during all the detailed stages of the work analysis.

MEANS-ENDS RELATIONS	PROPERTIES REPRESENTED
Purposes and Constraints	Properties necessary and sufficient to establish relations between the performance of the system and the reasons for its design, i.e., the purposes and constraints of its coupling to the environment. <i>Categories are in terms referring to properties of environment.</i>
Abstract Functions	Properties necessary and sufficient to establish priorities according to the intention behind design and operation: Topology of flow and accumulation of mass, energy, information, people, monetary value. <i>Categories in abstract terms, referring neither to system nor environment.</i>
General Functions	Properties necessary and sufficient to identify the 'functions' which are to be coordinated irrespective of their underlying physical processes. <i>Categories according to recurrent, familiar input-output relationships.</i>
Physical Processes and Activities	Properties necessary and sufficient for use of equipment: To adjust operation to match specifications or limits; to predict response to control actions; to maintain and repair equipment. <i>Categories according to underlying physical processes and equipment.</i>
Physical Form and Configuration	Properties necessary and sufficient for classification, identification and recognition of particular material objects and their configuration; for navigation in the system. <i>Categories in terms of objects, their appearance and location.</i>

Figure 12. The characteristics of the classes within the means-ends hierarchy.

	PATIENT		HOSPITAL		
	SOCIAL RELAT.	BIOLOGICAL	CURE	CARE	ADMINISTRATIVE
GOALS AND CONSTRAINTS	Working Relations and Conditions; Family Relations; Goals and Constraints of Plans and Commitments;	Effects of Illness and Treatment on Persons Ability to Meet Subjective Goals and Criteria	Cure Patient, Research, Meet Public Opinion within Economic, Legal and Ethical Constraints	Patient Well being, Physical and Psychic Care, meet Public Opinion within Economic and Legal Limits	Laws and Regulations; Society, Associations and Unions; Workers Protection Rules.
PRIORITY MEASURES, FLOW OF VALUES AND MATERIAL	Personal Economy, Probability of Unemployment, Cure, etc.	Probability of Cure, Priority Measures, Speed versus Side-Effects, etc.	Categories of Diseases: Cost of Treatments, Patient Suffering, Research Relevance	Flow of Patients according to category; Treatment, and load on staff and facilities	Distribution of funds on Activities; Flow of material and personnel to diseases, departments,
GENERAL FUNCTIONS AND ACTIVITIES	Nature of Work and Employment, Family Relations, Living Conditions;	General State of Health; Category of Disease and possible Treatments;	Cure, Examinations, Diagnostics, Surgery, Medication, etc. Research, Clinical, Experiments,	Board and Lodging, Feeding and Hygiene; Social Care, Physical Support, Transportation, etc.	Personnel and Material Administration, Accounting, Sales and Purchase;
PHYSICAL ACTIVITIES IN WORK, PHYSICAL PROCESSES OF EQUIPMENT	Physical Work Activities, Spare Time and Sports Activities; Home-Work Transportation, etc.	Specific Organic Disorders and their possible treatments, Previous illness and cures;	Specific research and treatment procedures; Patient Monitoring; Functioning of tools and Equipment	Specific Processes in Monitoring, Treating, Moving, Cleaning and Feeding Patients; and in Psychic Care.	Processes in the Administrative Functions, Office and Planning Procedures;
APPEARANCE, LOCATION & CONFIGURATION OF MATERIAL OBJECTS	Patient Identification, Age, Address, Position, Education, Identification of Close Family, etc.	Physical State of Patient, Weight, Height, Previous Treatment, etc.	Material Resources, Patients, Personnel, Equipment; Inventory of Medicine, Tools, etc.	Facilities and Equipment in patient quarters, kitchens, etc. Inventory of Linen, Food, etc.	Inventory of Employees, Patients, Buildings, Equipment, etc.

Figure 13. The figure shows a schematic overview of the work space of a hospital environment. For planning of the treatment of a patient, several different individuals and professions are involved. The person's medical practitioner has to consider the case in the patient's social and biological context; At the hospital, medical as well as social and practical 'hotel' functions must be considered and, at the same time, the requirements stemming from research needs and from the necessity of fitting the treatment into the financial and political context has to be considered. In total, taking care of a patient involves the consideration of several different 'object worlds'.

	System Properties to be Represented			
GOALS AND CONSTRAINTS	Finance Policy Manufacturing, Bonds and Investments Market Policy Custom-Design; High-Tech Consumer-Population Age, Education; Location Research Status Tax and Business Regulations Union Agreements Workers Protection Regulations Essential Company Policies Innovative, Advanced-Tech. Public Image Policy, Re-ability, Supplier-population Policy, Re-ability, Regulation of Branch Associations.			
PRIORITY MEASURES, FLOW OF VALUES AND MATERIAL	Flow of Funds Sources: Sales, Bonds, Interest Flow of Materials Sources: Suppliers Flow of Information Sources: Suppliers Flow of Equipment & Tools Supplier, Flow of Manpower Education, Company Training, Department, Function, Promotion, Retirement, Lay-off.			
GENERAL FUNCTIONS AND ACTIVITIES	Research and Development Follow State of the Art; Conceive new Products, Test Ideas;	Manufacturing Prepare for Production; Plan; Program Machines; Train Staff; Control and Monitor; Test and Pack;	Purchasing & Sales Accounting; Evaluate Suppliers; Predict Consumption; Market Evaluation; Production Schedules; Pricing;	Personnel Administration Hiring, Laying-off Salaries, Evaluation Planning Work Schedules and Shifts;
PHYSICAL ACTIVITIES IN WORK, PHYSICAL PROCESSES OF EQUIPMENT	Analyze Competing Products, Literature, Patents, Experiments; Prototyping;	Processes of Equipment and Tools; Planning Processes and Methods;	Accounting and Planning Tools; Spread-sheets & Budgetary Tools; Market & Sales Reviews; Statistics	Interviews; Re-negotiations; Schedules; Performance Reviews; Comparison; Promote;
APPEARANCE, LOCATION & CONFIGURATION OF MATERIAL OBJECTS	Library Items; Drawings; Equipment; Spec's and Location	Location and Spec's of Machinery, Buildings, Components, etc.	Suppliers and Customers, Identification; Location; Product and Raw Material Spec's and Inventories	Personnel Identification and Characteristics, Salary Lists; Addresses, Family Information; Transportation Information; Vacancy Lists;

Figure 14. Shows an example of a work domain from a manufacturing company

Classes and Terminology of Work Domain

Two aspects of the taxonomy within the work domain representation should be explicitly considered. One includes the classes and terms used for description of the structure and the relationships of the domain. Another includes the elements used to characterize the domain within the different levels of representation.

1.1 Work Domain Description: Its Structural Relationships

Coupling to the Environment

In the previous section, the coupling to the environment was discussed in terms of system goals, purposes, and environmental constraints at this level. It is, however, clear that coupling to the environment is found at any of the levels of the means-ends hierarchy in varying degrees. Basically, the 'system' is defined as a subset of the world, and the cut will intersect all levels. The means-ends representation, therefore, can be useful for further identification of the constraints presented by the coupling to the environment.

a. Functional Coupling

The level of abstraction on which tight coupling to the environment is found, depends very much on the nature of the enterprise:

In some cases, tight coupling is found at the level of physical form: a company may supply physical items and components which must match quantitative physical *configuration specifications*: spare parts for cars, equipment for military systems, etc. Other companies are supplying equipment for *specified processes* such as typewriters, word processors, or they are offering services in terms of specific physical processes, such as, e.g., electric power supply, surgery, dental care.

In this case the *process*, not the material configuration by which it is implemented, is specified. In some systems, such as offices, manual production workshops, etc., physical processes need not be synchronized. Coupling is necessary only in terms of their longer term effects i.e., coupling is only required in terms of *general functions*; depending on decoupling by storage facilities, queues, piles, etc. in the boundary to the environment

In other cases, the coupling to the environment is specified at the more abstract function level related to the flow of monetary values, information, and people, such as banking and tax revenue systems, educational systems, public transportation, etc. In some cases, the coupling of a system is even only specified at the highest level of values and goals without any request for the lower level implementations. Examples could be entertainment business, religious services, artistic professionals, etc.

The level at which tight coupling to the environment is found has strong influence on the level and degree of detail of the knowledge which is required about the activities and state of affairs in the environment which is required for control of activities within the system itself.

b. Formal Coupling: Constrains Implemented in Rules, Laws, Agreements

Propagation of goals and constraints top-down through the levels of the means-ends hierarchy is not a causal, nor a teleological effect, but rather more like an evolutionary selection. High level goals such as acquire a high salary for union members and, at the same time making sure the working life qualities are satisfactory in a working situation requires reformulation and operationalizing down through the levels. Simple deductive transformation between levels is, however, not generally possible due to the large increase in variety going downwards. Instead, empirical trial and error and selection of positive rules of the trade are made. This implies, in stable environments, that the influence of high levels goals and constraints are replaced by operational, formal constraints in the form of stored rules of action at the lower levels. This in turn means, that high level goals and constraints are inactive during familiar circumstances and replaced by standard practice rules. This however, does not imply that the higher level goals and constraints are not shaping behaviour; only that this shaping is evolutionary through selection, i.e., “survival of the fittest rules”, just like “survival value” is shaping biological behaviour without affecting the particular observed behaviour directly.

Features of Coupling to the Environment

Some examples will serve to further illustrate features of the coupling to consider:

Nature of coupling, i.e. the kind of product or service to be provided: The service given the environment can depend on supply of products (manufacturing), on services (telephone companies, schools, hospitals).

Character of coupling, i.e., the way by means of which the requirements of the environment is conveyed to the organization. For instance, requirements may be conveyed explicitly, e.g., by governmental statutes, contractual stipulations, etc., or by the negative and positive reactions of the market.

Locus of control of environmental coupling. Another dimension to consider is the following: Who is in control of the coupling? Who paces the system, the environment in terms of competitors, authorities, customers? What kind of time horizon is involved? Is control negotiable or one-sided? Is the coupling controlled from inside the system or from the environment?

Stability or variability of functional requirements, i.e., the extent to which the conditions under which the system of work must function change and the system have be able to adapt to such changes (Thompson, 1967; Scott, 1987), e.g., changes in the function of the organization (nature, characteristics, quality of its products, services etc.) that occur unexpectedly, for which no patterns could have been discerned in advance (Mintzberg, 1979). Are the features of the environment defining the goals of the system fairly stable (power plant), or are they dynamically changing (manufacture of personal computers and ladies' fashion)? The stability and predictability of the processes and states of affairs is an important feature of a

work domain and its coupling to the environment. In manufacturing, for example, the duration of product life cycle of the specific market is a measure of the stability of functional requirements, e.g., custom tailoring vs. commodity markets.

Unified or diversified functional requirements, i.e., the extent to which the environmental requirements are similar to one another, e.g., the size of the product mix (number of models and variants offered by the company), the complexity of product quality specification etc. (Mintzberg, 1979; Scott, 1987; Aoki, 1988)

Interdependency of requirements, e.g., competing requirements. (Scott, 1987).

Specificity or ambiguity of requirements. Can the main goal be explicitly stated in terms of functions (power plant, telephone company) or is it only qualitatively identified in terms of values (hospital, theater, university, etc.).

Hostility vs. munificence of environment, i.e., the degree to which the system of work is vulnerable to its environment (e.g., by the intensity of the competition, by the precariousness of its funding), and the degree to which errors by an organization may result in its demise (e.g., the security demands posed on chemical and nuclear power production, or on policy making agencies) (Scott, 1987). Does the system face a competitive environment (manufacturing companies, service enterprises); does it, in practice, have a monopoly (public health service, hospitals); or is it based on legal monopoly (Danish power companies and telephone networks).

Intrinsic Work Domain Characteristics

In order to be able to compare results from field studies in different domains and to transfer results to studies in new domains, it is necessary to establish a multi-facet system for description which is independent of the particular elements of a domain (cf. Hammond's arguments for the necessity of modelling the 'formal structure of a task' as a basis for analyzing behaviour, Hammond, 19??). Furthermore, for such a descriptive framework, it is important to common to or compatible with a similar framework for micro-worlds serving experimental studies. The dimensions considered in the following are proposed for further development within the MOHAWC project and some of the dimensions proposed by Brehmer (1990) have been taken into consideration. The dimensions to include and the categories of the dimensions should evolve dynamically through the coming studies and efforts to generalize. The list below should only be taken to be a starting point and a basis for discussions of the structure of the taxonomy.

Complexity

Complexity of a work domain is an often discussed and rather elusive concept. The term covers typically both very subjective features which are depending on the level of abstraction and the degree of aggregation within the mental representation hold by an agent (Rasmussen, 1986, pp. 117-120), and features of objective complexity as discussed by Pedersen (1990). In the present context, a more pragmatic conception of complexity may

be useful to capture broader perspective. Features to consider for description of the complexity of a particular work domain or micro-world would be features such as

1. *The size of 'problem space'*, i.e., the number of different, potentially relevant factors to take into account (Simon, 1969). For example, in contemporary medicine, the number of identified illnesses - and hence, the number of potential diagnoses, amount to approximately 500.000. In portfolio management, decision makers face the immense volume of investment object on the world markets.
2. *The variety of functional elements* within the system, i.e., whether a large number of similar items (books in a library) or a large number of different items (equipment of a hospital).
3. *Number of goals and objectives* of a system;
4. *Compatibility of goals and constraints*, i.e., whether constraints are tight around goals and require careful navigation or not or whether goals are contradictory and invite conflict or not;
5. *Number of functional elements* of a system which are coupled and require simultaneous attention;
6. *Number of connections* among elements;
7. *Uniformity or heterogeneity of the work space*, i.e., does decision making involve the integration of knowledge from different object domains, integration of different conceptualizations or perspectives (Mintzberg, 1979; Rasmussen, 1987; Schmidt, 1988).

Integration

Another dimension of the description of a work domain which has caught considerable attention, in particular within modern manufacturing, is the degree of integration of a system, 'computer-integrated manufacturing' has been a controversial topic for several years, cf. the introduction, pp. 15 f. System integration is a much discussed feature of advanced manufacturing systems which is, however, not in general very well defined. Typical features of 'integrated systems' are rapid responses, continuous product flow rather than batch processes, and effort to avoid stocks and piles between processes, i.e., effort to keep the inventory 'in process' low. Basically, integration means increase of the intrinsic coupling, which can be measured by the number of links, the strength of the coupling, and the time response required. A measure of system integration in terms of the requirement for internal coupling is important because it greatly influences the request for inter-agent coordination and the resulting (informal) social organization. The following list of features of integration has been identified from several meetings considering problems within 'integrated manufacturing' and can serve as a starting point for further work:

1. *Functional Structure*. This feature represents the functional structure of the 'integration,' i.e., of that part of a system which is considered to be functionally connected. Some basic categories can be suggested, such as functionality involving 1) *interaction among separate objects*, more or less stable (e.g., manufacturing of pieces of

equipment, navigation in traffic), 2) *control of a continuous, linearly constrained flow* (of energy in a power plant, of products in continuous production). Within this category, different flow structures can be found, such as i) a river-structure (manufacturing and assembling products depending on many component sources); ii) an inverse river structure (several product repertoire from forced input (Oil refinery, Steel refinery) and, iii) parallel flow (patients in hospitals). Finally, work domains are found which have a *continuous, distributed flow in several dimensions*, such as control of the temporal, spatial properties in forest fire fighting, control of epidemics, weather forecasting, etc.

It is important to realize, that the same system can be represented within several of the categories depending on the level of abstraction applied for representation, e.g., whether a manufacturing system is characterized by passing objects or by flow of products depend upon the interpretation chosen.

2. *Nature of connections* is another important characteristic. Interaction within the structures listed can depend on 1) material transport; 2) a physical process; or 3) on propagation of information which, in turn can depend on communication of i) goals and constraints; ii) procedures and instructions for action; and, finally, iii) by supplying advice.

3. *Tightness of connection* can vary widely within the structures defined above and categories such as the following can be suggested: 1) Hard coupling, direct functional connection (e.g., as is found in a chemical process plant or a football match); 2) Moderate coupling, i.e., the individual elements are decoupling by means of queues, piles, etc. (Batch production, office work), and, 3) Loose coupling, considerable decoupling by long term storing.

4. *The level of tight coupling*. The level of abstraction in the means-ends hierarchy where tight coupling is required is a characteristic feature of a work domain. In some cases, a tight coupling is required only at the 1) *material configuration* level, as it is the case in mechanical, structural designs such as bridges, towers, etc. Coupling can be found in terms of i) anatomical connection or of ii) topographic proximity. 2) In many cases, however, tight coupling is required at the *physical process* level. Good examples are process plants such as power plants in which the interaction among the physical processes in oil burners, boilers, steam generators, turbines and electrical generators must be tightly coupled in a very short time horizon. Energy flow must be maintained through all the different processes involved. A lack of coordination will result in accumulation of energy resulting in high temperatures or pressures leading to accidents. (In practice, the coordination requirement will be so tight and fast that only automatic control can meet the requirements properly). Other examples can be work spaces on an assembly line or a “just-in-time” production system, a transport system with tight time schedules, etc. Coupling of physical processes can take place by i) Physical interaction or by ii) exchange of information. 3) In other cases, coupling is only required at the more *general function* level, as it is the case in a traditional manufacturing system. In this case physical processes need not be coordinated, only the input and output quantities of the various functions needs to match over a somewhat longer time horizon, determined only by the size of the stock keeping accepted for decoupling of the functions involved. This is the normal pattern for workshops and offices, shops, etc. Also at this level, coupling of general

functions can depend on i) transportation of products and material or by ii) exchange of information

5. *Predictability of coupling.* The predictability of the intrinsic coupling is an important feature for work planning. 1) systems with stable coupling (breakdown and disturbances are infrequent, average performance counts); 2) Systems which are by and large stable, but unpredictable disturbances are critical (e.g., high hazard process systems); 3) Systems of intrinsically stochastic nature (patient treatment in hospitals).

6. *Temporal requirements* of the functional integration which can be 1) fast in the high tempo operation of air craft take down on a carrier, 2) moderate operations in an office, 3) slow processes of growing vegetables or 4) the very slow changes in an economic environment or a legal system. These aspects are very important for the opportunity for actors to develop temporal intuition and categories probably be related to this basic human ability. (The preferred dynamic range for human actors is somewhere between the dynamics of a sports game and of a super tanker?)

Source of Regularity of Behaviour of a Work Domain

Within the system itself, human activity can be called for at any level of the means-end hierarchy and can be controlled either by know-how and rules of the trade or by analysis and planning depending on the situation. In all cases will the opportunity to plan depend on knowledge of the sources regularity of behaviour of the resources at disposal. One important feature of the elements at any level of the means-end hierarchy will be whether regularity depends on 1) stable laws of nature (technical equipment, physical objects, etc.); on 2) human intentions (social systems, systems designed for certain purposes and having complex and autonomous features (e.g., computer programs, expert systems), or they are controlled by formal, context free rules (games and puzzles, cryptograms, etc.).

In many man-made systems, the source of regularity of behaviour is the *laws of nature*. Systems are designed so as to define some material boundary conditions within which the laws of nature are constrained to performed the goal oriented functions. For such systems, prediction of their behaviour in response to control actions can be inferred bottom-up from their functional structure.

Not all systems, however, can be considered this way. Systems with a high degree of autonomous internal functioning, with self-organizing and highly adaptive features, may change their internal functional organization frequently in order to meet the requirements of the environment and to suit their internal goals or performance criteria. Even though such systems are basically causal and controlled by laws of nature, their complexity makes it impractical, if not impossible, to explain or predict their performance by functional analysis during real-life decision making. The alternative is to consider such systems as *intentional systems*, controlled in their response to external influence within their range of capability by their “intention” to act derived from the individual value structure and internal goals. Decision making in control of intentional systems is based on knowledge about the value structures of the system, the actual input from the system’s environment, and its internal limiting properties; i.e., it is based on reasoning top-down

in the abstraction hierarchy with little or no consideration of the internal causal structures or functions. This is probably the reason why top-level executive decision makers, according to Mintzberg's study (1973), do not behave according to analytical decision models, but prefer live action and social contacts to the analysis of abstract information and current data—even gossip and hearsay— instead of statistics and status reports. Meeting people and considering hearsay are probably the best sources of information on current trends in value structures.

The distinction between physical causal systems and intentional self-organizing systems must also be considered if results from research in human performance in games (for instance from artificial intelligence research) are considered for use in models of human interaction with physical systems. In two-person games like chess, a person faces a system that is not controlled by basic invariant laws but by the intentions and value structures of the opponent. The game itself only represents a means of communication, and the rules of the game serve only to constrain the decisions of the players to a well-defined set in each situation. Decisions depend upon prediction of the opponent's value structures and performance criteria and the strategy he adopts for the game. The difference between games like chess and other social-system contexts for management decision making is largely a question of formal consistency and invariance of the rule set. In games, the set of rules at the problem level is small and closed, and only the strategies for generation of proper action sequences are flexible and depend on top-down inferences regarding the opponent's intentions. In management decision making, there is room for the invention of new rules of the game within the constraints of legal rules and "fair play."

Formal systems for decision making are problems that are only defined at one single level of abstraction, such as geometrical theorem proving and construction, cryptographic problems, puzzles, and purely logic problems; see for instance Newell and Simon (1972). The problem is stated here as an initial state and a target state, and the task is to identify a sequence of allowed formal transformations which will close the gap. The category of formal systems also includes several of the "context-free" tasks, which are used for problem-solving and man-machine interface experiments. It should, however, be realized that problem solving behaviour may be very different in one-level formal systems and in a problem context of an abstraction hierarchy.

An illustrative example of the role of the abstraction hierarchy can be found when comparing a decision task that has to be performed in a one-level formal description with the performance when the context is also available. The difference may partly be due to the use of shifts in the level of abstraction to find paths for transfer of solutions and strategies by analogy, but also due to the support of memory and search for rules in terms of structures at other levels of abstraction. A good empirical piece of evidence is the experiment made by Wason and Johnson-Laird (1972). This experiment was based on a set of cards which were hypothesized to represent the concept: if one side shows a vowel, then the back side displays an odd number. A subject was given a sample of four cards and asked which should be turned over in order to test the hypothesis. The experiment was repeated with the same concept disguised in a bill-signing context: if the amount of a bill exceeds \$50, the supervisor must sign the back side. The ratio of correct solutions in

this kind of experiment is typically 13 percent to 70 percent. In the first experiment the problem-solving is based on formal logical arguments at only one level of abstraction; on syllogistic logic, which requires manipulation of abstract symbols; and on storage of intermediate results in short term memory. In the second experiment the context defines an intentional system, in which the effects of the different decisions can be inferred very easily at the higher levels. The reasons for proper states can be inferred “top-down.” The problem is solved by top-down model modification; that is, by transferring to a model of “reasonable states of affairs.” Such experiments points to the importance of this dimension of the taxonomy.

MEANS-ENDS RELATIONS	INTRINSIC COUPLING WITHIN BASIC WORK DOMAIN	COUPLING TO ENVIRONMENT
Goals and Purposes, Constraints.	Coupling only on the level of goals and values without considering coordination within the system itself is found in some systems. Examples can be political campaigns, religious movements, etc.	Intentions; Mutual Acceptance of Goals, Values, and Requests
Priority Measures; Flow and Accumulation of Mass, Energy, Information, People, and Money.	Loose coupling depending only on abstract value measures such as economy without consideration of the underlying functionality or content is adequate for systems such as commercial outlet chains, industrial corporations, etc.	Exchange of Mass, Energy, Values, Manpower, etc.
General Functions and Activities.	In some systems, such as offices, manual production workshops, etc., physical processes need not be synchronized. Coupling is necessary only in terms of their longer term effects i.e., coupling is only required in terms of general functions; depending on decoupling by storage facilities, queues, piles, etc.	Coordination of Functions
Physical Processes in Work and Equipment.	Integrated technical systems, such as industrial process plants need tight coordination at the physical process level: Physical variables must be closely controlled and coordinated for proper system function. Temporal synchronization is essential.	Coupling of Physical Processes
Appearance, Location, and Configuration of Material Objects.	Coupling at this level is essential for structural support systems, such as bridges, scaffolding, buildings, etc.	Anatomy and Topography of Physical Connections

Figure 15. The co-ordination of functions required by a control function for concerted system function depend very much upon the intrinsic coupling within the work domain. The lowest level at which co-ordination of the entire system is required depends upon the nature of the activities in the system.

Transparency

An important characteristic of a work domain is the transparency, i.e., the degree to which the functionality is observable by the actor. In some cases the functionality is 1) *directly visible* as it is the case in a natural environment of object manipulation or in machinery based on mechanical processes. In other cases, functionality is 2) *invisible* and only accessible when mediated by an interface. Several categories of transparency can be formulated, such as i) Symbolic interfaces; ii) direct perception interfaces based on ecological invariants and iii) metaphor-based interfaces.

Discussion

The tightness of coupling at the various levels in the boundary to the environment is frequently reflected in the intrinsic coupling within the system. The significance of the kind of coupling within a system and through its boundary was also considered by Thompson (1967). In order to understand the actions of complex organizations, Thompson applied a rather crude distinction: 1. 'Long-linked technology' covers sequentially dependent acts, e.g., assembly line technology for standard products, based on repetitive processes. This is the domain of scientific management. 2. 'Mediating technology' serving a population of clients; insurance companies, bank, etc., requiring operating in standardized ways, i.e., bureaucratic techniques of categorization and impersonal application of rules. 3. 'Intensive Technology' in which a variety of techniques are brought into action on some specific object, hospital, construction industry, military combat teams, etc.

A stratified description of an enterprise in order to determine the influence of its internal structure upon the organizational behaviour has been proposed by Parsons (1960) who suggests that organizations exhibit three distinct levels of responsibility and control: technical, managerial, and institutional. This distinction is very similar to the stratification in terms of means-ends relations proposed here. Every formal organization has sub-organizations whose 'problems' are focused around effective performance of the technical functions - teachers conduct classes, the bureau processes income tax, and handle recalcitrants, workshops process material and supervise operation. The managerial level services the technical sub-organizations. It mediates between them and their customers, pupils, etc., and procures the resources and supplies. The managerial level controls, i.e., administers the technical level. Finally, the institutional level is the source of the *meaning* of the entire enterprise, it supplies the higher-level support to make the organization's goals possible. Parson's reasoning leads to the expectation that different technical functions- or technologies-cause significant differences among organizations and, consequently, Thompson (1967) stresses the need to include the control of the physical work domain in the organizational model: "The technical parts of the system provide a major orientation for the social structure. There are both instrumental and economic reasons but the instrumental question is prior to that of efficiency."

For the representation of *goals, purposes and constraints* representing the coupling to the environment, a number of categories to look for and attributes to list can be found in the existing literature: The approach to organizational and management models represented by Thompson (1967) is compatible with the framework discussed in the previous sections. His basic point of view is that of an adaptive evolution of an organization 'under the assumption of rationality.' In order to characterize the adaptive behaviour of an organization, Thompson finds the most important characteristics of the coupling to the environment to be *the degree of homogeneity and stability of the environment*. During adaptation homogeneity influence organization structure in the following way:

"Under norms of rationality,

- organisations facing heterogeneous task environments seek to identify homogeneous segments and to establish structural units to deal with each.

- boundary-spanning components facing homogeneous segments are further sub-divided to match surveillance capacity with environmental action.”

Discussing the influence of environmental stability on the adaptation of an organization and its agents in terms of work strategies, Thompson make distinctions which are very similar to the distinctions presented in the subsequent section on cognitive control:

- “- The organisation component facing a stable task environment will rely on rules to achieve its adaptation to that environment.
- When the range of variation presented by the task environment segment is known, the organisation component will treat this as a constraint and adapt by standardising sets of rules. (This is an empirical categorisation routine typically used by bureaucratic organisations: bureaucratic procedures are based on categorising events and selecting appropriate responses).
- When the range of task-environment variations is large or unpredictable, the responsible organisation component must achieve the necessary adaptation by monitoring that environment and planning responses, and this calls for localised units.”

This reference to Thompson’s discussion illustrates the need to develop the classes and terminology based on an iterative consideration of the various dimensions of the taxonomic framework.

1.2 Work Domain Description: Representation Of Its Elements

Definition of classes and terms within the work domain will be imported from the professions relevant to the actual work domain, i.e., engineering, management and organization, administration, policy and social science, etc. Classes and terms from several different professions will frequently be necessary to cover the various levels of the means-ends landscape of work. The layered structure itself of the work domain description should be related to similar conceptualizations which have been found in management and organizational theories (e.g., by Parson, Thompson).

Level of Goals, Values, and Constraints

The concepts and terminology at this level representing the interaction between the system under study and the general society is rather general, only the focus and selection of terms characterize a specific analysis.

Level of Abstract Functions and Priorities

In order to compare the effect of the various functions involved in system operation on the various goals and constraints, it is necessary to adopt some *value measures* that can be applied independent of the particular functional implementations. The abstract value measures generally can be assumed to follow conservation laws. Values in a system is depending on monetary values, material and mass, energy, people and neither of these values are supposed to disappear uncontrolled, either by virtue of the first law of thermodynamics or in consequence of social conventions and laws. Conservation laws, consequently, will be guaranteed either by nature (thermodynamics) or by legislation. Efficiency measures, reliability, probability, and information theoretic measures are quite naturally connected to the description of distribution, flow accumulation and conservation of values at this level.

Since this level takes care of measures which can be applied across a wide variety of general functions, the categories of a taxonomy also will be rather independent of the particular kind of system. Maybe even more so than the level of purpose and constraints which is related to that slice of the environment which is relevant for the particular activity of the system considered.

Level of General Function

At the level of general function one can expect to find function categories which are common to most systems, such as e.g., personal administration, marketing, etc., while others are peculiar to a particular kind of enterprises, such as e.g., design, production planning, maintenance which are found in all manufacturing systems.

Physical Processes

The categories useful to describe the activities at the level of physical process level will be closely related to the basic work activities and tools applied in the system,. The selection will be characteristic of particular work place and the adopted work practice, but the set will be a subset of the terminology applied by the professions involved.

Discussion: Systematic Professional Terminology

A useful, illustrative example is a systematic taxonomy which has been proposed by Alting (1978). He suggests a morphological process model to support integrated planning of design and manufacturing, which is a multi-level model with basic features similar to the means-end hierarchy considered in the present approach.

At the most general level corresponding closely to the *level of abstract function* in the present framework, Alting characterizes manufacturing processes in terms of the three associated flows:

- a) material flow,
 - b) energy flow, and
 - c) information flow.
- a) *Material flow* can be divided into three main types:
- * *through flow*, corresponding to mass-conserving processes, in which the mass of the initial work material is equal to the mass of the final component, and the material is manipulated in order to change the shape;
 - * *diverging flow*, corresponding to mass-reducing processes, in which the shape is obtained by removing material from the initial material that circumscribe the final shape.
 - * *converging flow*, corresponding to assembly or joining processes in which the shape is obtained by joining pre-shaped parts, without removing material.

This discussion is related to the flow of material, other flows will be involved depending on whether the processes are carriers of energy or information.

- b) *The energy flows* associated with the process can be characterized in terms of energy supply, energy transmission to the work material, and removal or loss of energy.
- c) *Information flow* includes what might be termed shape or property information. Shape information can be transmitted by:
 - * contours in the interaction between work material and tool (die), or by
 - * patterns of movements of a tool.

This means that, at this level, “a geometry-changing process is characterized by a material flow on which, by means of an energy flow, the shape-changing information corresponding to the information flow is impressed” (Alting, p.133).

At the next lower level, similar to the *level of general functions*, the primary basic processes are represented, for instance, in the three groups mentioned:

- * forging, rolling, powder compaction, casting;
- * turning, drilling, milling, cutting;
- * welding, brazing.

Next, the level of physical function contains the processes applied for implementation. Casting, for instance, can be implemented by sand casting, die casting, centrifugal casting, dip casting, etc., categories which clearly refer to the underlying physical process.

At the level of *physical form*, the physical appearance and the material characteristics of the equipment will be represented. Also at this level, a systematic terminology is found in all professions, at least in the form of manufacturers' or products' names for standard models.

Alting concludes his description:

“all manufacturing processes can be described by a morphological model made up of a material flow, an information flow, and an energy flow.-- In practice it can be used in the generation of alternative production methods for a given component and it can be used in process development. Both the design and manufacturing engineer have, in this approach, a new and powerful tool. If one considers the rapid increase in the application of computers in design and in manufacturing, the new systematic approach fulfils the long existing need for a coherent and systematic ‘theory of manufacturing’.”

He adds, that the principles are valid for all types of manufacturing methods, including processes in mechanical, civil, electrical, and chemical engineering.

In the present discussion of a taxonomy for analysis of work performance, it is important to consider that such different classes of manufacturing technology can have significant influence on the constraints shaping work performance, and adoption of a proper professional terminology from the actual domain can be important for communication with professional people from the domain and among research teams. It will be different to get advice from domain experts unless a consistent standard terminology which can be found in standard text books is used.

1.3 Work Domain Description: Identification of Agents

The work domain representation is well suited to give an overview of the involved classes of agents with reference to the functions which are normally allocated to them. Typically, this general allocation will follow the particular agents professions, but this has to be verified in the particular cases. The overview will be useful for planning the subsequent, more detailed analysis. The following two figures 16 and 17 show the typical difference as it can be found between a hospital and a production company. In a hospital, as it is also the case for e.g., universities, the professional staff covers functions from the lowest to the highest levels, whereas in a production company, the organizational structure is traditionally hierarchical.

The figures also illustrates how such representations can indicate topics for more detailed analysis. In a production company acting in a dynamic and competitive environment, it is essential for policy making and strategical planning of product development, that high level management can judge the role of company product in the functional customer context and the implications for the internal production environment, see figure 17. This is difficult to do effectively for top level management in the hierarchical organization if, as is typically the case, they are recruited from business or law schools. In hospitals, the substance matter experts take part in the strategical planning and is familiar with the “customer” context.

	PATIENT		HOSPITAL		
	SOCIAL RELAT.	BIOLOGICAL	CURE	CARE	ADMINISTRATIVE
GOALS AND CONSTRAINTS	Working Relations and Conditions; Family Relations; Goals and Constraints of Plans and Commitment	Effects of Illness; Treatment on Ability; Medical	Cure Patient, Research, M. Public Op. within Ec. Legal and Constr.	Patient Well being, Physical and Psychol. Care, meet Ex. Education, mi	Laws and Regulations; Society, Ass. and Workers Rules.
PRIORITY MEASURES, FLOW OF VALUES AND MATERIAL	Personal Econ. Probability of employment, etc.		Catego. Diseases, Treatm. Suffer. Relev.	General Manage	Head Nurses
GENERAL FUNCTIONS AND ACTIVITIES	Nature of Work; Employment; Family Relations; Living Conditions	Medical Practitioner	Cure, Diag. ry, M. Rese. Expe.	Medical Doctors	
PHYSICAL ACTIVITIES IN WORK, PHYSICAL PROCESSES OF EQUIPMENT	Physical Work; Activities, Spare and Sports Activities; Home-V. Transportation		Speci. and tr. procedur. Monitoring; Equipm.	Nurses	
APPEARANCE, LOCATION & CONFIGURATION OF MATERIAL OBJECTS	Patient Identification, Age, Address, Position, Education, Identification of Close Family, etc.		Mat. Equip. Inven. cine, To	Assistent Nurses	Inventory of Employees, Patients, Buildings, Equipment, etc.

Figure 16 The allocation of functions within a hospital displays some very characteristic features. The medical doctors are covering the entire abstraction span of the means-ends hierarchy. They are involved in the actual physical treatment of patients. At the same time, they will be involved in the interaction at the goal and purpose level, being involved in research, teaching, strategical planning and debate about priorities and values in medical care.

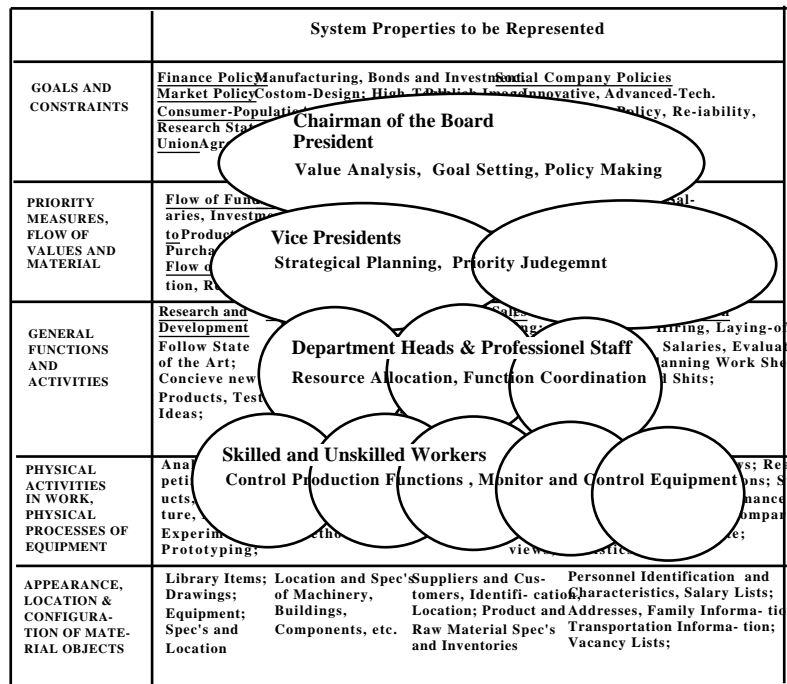


Figure 17 Example from Production Company

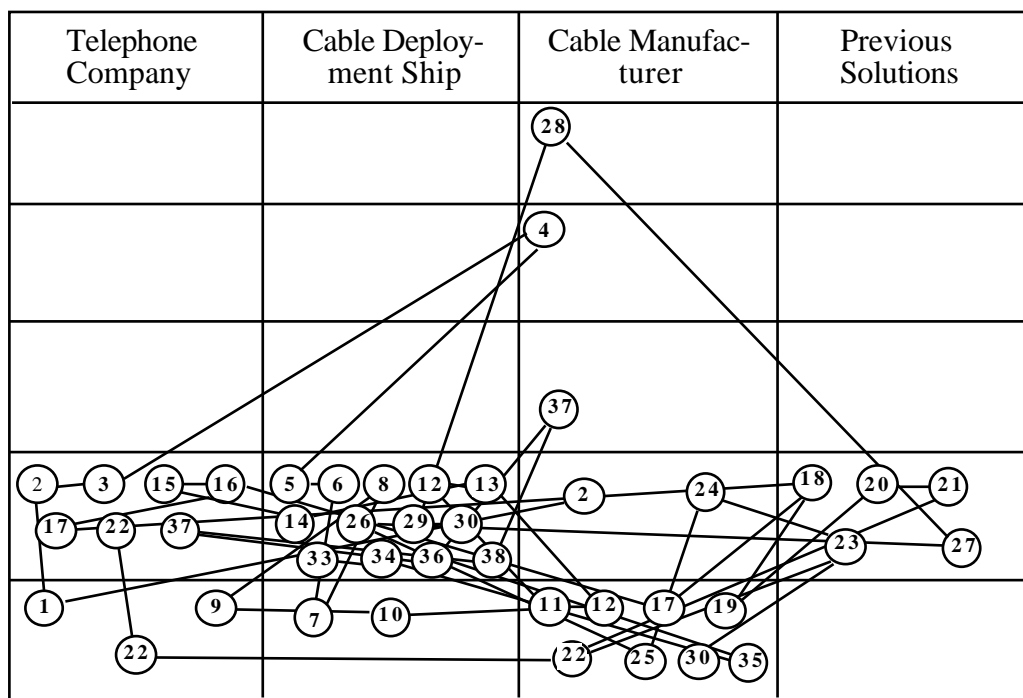


Figure 18. In many work situations, several different work domains must be considered and the task will be to establish the conditions under which the effect of decisions are acceptable in the various domains. The figure shows the trajectory in the work domain of a design task: the design of a cable joint for optic fiber telephone cables. In this case, the object of design belongs to different 'object worlds:' it is a joint in a telephone cable, it is part of an assembly task under rough sea conditions, and, finally, it is an object to be manufactured by the equipment of the cable manufacturer. The figure is only meant to be illustrative. For details, see Rasmussen, 1988.

Analysis Of Work Domain Activity

The work domain description discussed in the previous section is a stationary representation of the options for the choice of means for certain ends, an inventory of options for the agents to choose from in particular situations. It will, in general, be very complex simply because the particular means-ends relationship necessary to cope with any situation should be included in this representation. In order to be able to study features of the work domain shaping the behaviour of the human agents involved, it is necessary to focus on defined parts of the human activities. The criteria for this decomposition depends very much of the actual case. However, whatever the decomposition chosen, it will serve to select or ‘instantiate’ a subset of the elements and relations of the general work domain description, i.e., it will focus on a part of the general description which will then have to be explored in more detail.

Decomposition of Domain Activity

The interaction of people with the work environment and mutually in cooperative work is a more or less integrated and dynamic pattern. In order to analyze behavior it is necessary to decompose this pattern into meaningful elements which are manageable for separate analysis. Traditionally, this is done in terms of *tasks* which are then analyzed by task analysis generating a description in terms of a sequence of actions or activities. In the introduction it was discussed why this is no longer an adequate approach when response to task requirements is discretionary, involves flexible cognitive processes, and depends on subjective preferences.

In this situation, activities must be decomposed and analyzed in terms of a set of problems to solve, or a set of task situations to cope with, depending on the properties of the actual work domain. In hospitals, for instance, it appears to be a convenient decomposition to analyze in terms of “prototypical decision situations,” because many decision and planning tasks are depending on scheduled meetings and, therefore are well defined in time. In other cases, activities cannot be clearly delimited in time, and activity elements are more adequately defined in terms of a problem to solve, i.e., an activity element characterized by its content independent of its being spread out in time as, e.g., in manufacturing, the problem of “monitoring the resources for complying with a particular order.” The outcome of this analysis should be the identification of “prototypical” activity elements which, in varying combinations, can serve to characterize the activity of the agents of the system. As mentioned, in the hospital case, this can be done in terms of prototypical task situations, see figure 19. In manufacturing, however, such clear decomposition with respect to time is not possible, and a decomposition will instead be with reference to the function performed through time (note, that in both cases, the label of the elements are related to the function performed, but the basic decomposition criterion is different.

Once decomposed, the activities must be ‘articulated’ in the sense that the numerous tasks, clusters of tasks, and segments of the trajectory of tasks are to be linked together and the efforts of individuals and ensembles are to be meshed, etc. (Strauss, 1985). In

the words of Gerson and Star (1986), articulation consists of all the tasks needed “to coordinate a particular task, including scheduling subtasks, recovering from errors, and assembling resources.” The term ‘articulation’, as suggested by Strauss, Gerson, and Star, has different connotations than ‘coordination’ in that focuses on the *joining of different activities in terms of content* whereas ‘coordination’ emphasizes allocation and scheduling of adequate resources. The different forms of articulating domain activities need further investigation and is a precondition for the role configuration and division of work discussed in the section on Work Organization (section 5).

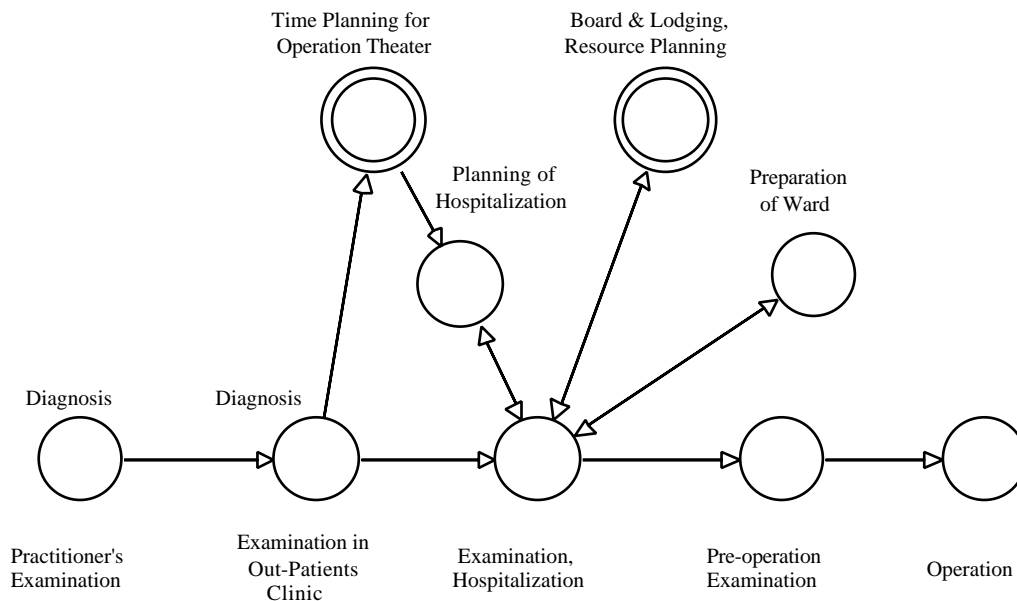


Figure 19. Example from a hospital. In order to determine the cognitive tasks to perform, particular activity elements must be defined and characterized by means of an activity analysis. It appears that no such thing as a ‘typical work situation’ or a ‘normal work procedure’ exists in many modern work domains. The analysis should be based on analysis of actual performance in particular situations, and rather than a description in terms of a sequence of actions, the analysis should identify a *set of situations or problems which can serve to define the relevant categories of work functions and, subsequently, the related decision tasks together with the required knowledge-base*. In the hospital context, the definition of prototypical activity elements are typically based on a decomposition with respect to time, in terms of prototypical task situations.

Delimitation of Domain Activity

For each of the activity elements defined in this way, it will be necessary to characterize *the activity in terms referring to the content of the work domain* because this is the language used by the agents, and will be necessary for analysis of the work and role allocation discussed in a subsequent section. The delimitation in this level of description defines the space of actualities, i.e., it highlights the relational structure within the means-ends map which is relevant for the situation at hand. In this way, the options relevant for action are drastically decreased in time and with respect to relevant goals and constraints as well as by highlighting the sub-set of the means-ends space of immediate interest. In this way, the space of functions and processes potentially of interest for control are defined, i.e., the goals and constraints which are shaping behavior and the means which

should be considered, irrespective whether the control is to be performed by one or more human agents or by computer control.

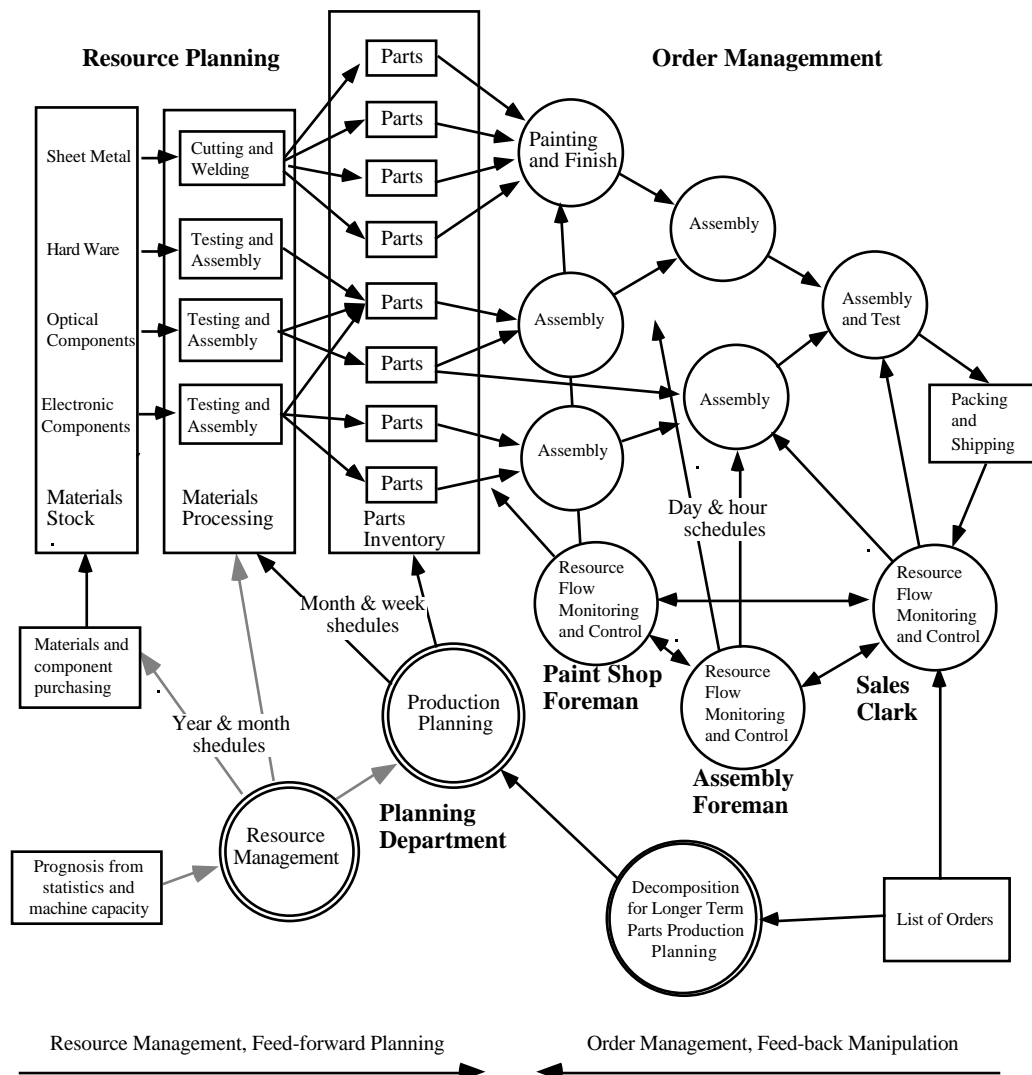


Figure 20 This figure illustrates the decomposition into prototypical activity elements for further analysis in a manufacturing system. In this case, decomposition with respect to time is less pronounced, and is typically done with reference to work function, related to identified organizational units or teams, (individuals).

Analysis

Such prototypical situations are identified from a detailed description of a number of actual task sequences, e.g., the specific situations found in the passing of particular patients through a hospital, or of a project through a manufacturing company. The descriptions of the specific work scenarios are collected by interviews concerned with very specific work situations. This is necessary to capture the actual important details and work heuristics and, at the same time, very effectively serve to facilitate the interview in calling for specific episodic and anecdotal evidence from the interviewee. Based on a set of representative case stories, the prototypical decision situations are then identified by analysis

across the work scenarios to identify situations which are similar with respect to a number of characteristics such as the number and competence of people involved, the parts of the work domain within actual attention, the familiarity of the task situation, etc.

Application

It is important to realize that ‘a typical task sequence’ will not normally exist in a modern, advanced work setting. In consequence, generalization cannot be made in terms of work procedures found by a classical task analysis. Generalization should be made at the level of prototypical decision situations which can be used, in different combinations, to describe the elements to be considered in the design of an appropriate information system for a particular work situation. In addition, the analysis will identify the individual agents involved in the prototypical decision situations, their roles and professional competence which, in turn, serves to identify their individual information need with respect to the work space representation in information systems.

Classes and Terminology of Activity

In conclusion: In the activity analysis, two descriptions based on different terminology are applied in order to obtain a closer delimitation of the behavioural options which are to be considered by the agent of a socio-technical system:

First, the relevant set of options are bounded by an identification *in time* of the task situation and *within the domain* of the relevant means-ends relations. In this analysis, the task is described in terms of operations on the work domain elements. Consequently, as it was the case for description of the work domain, the terminology will be widely accepted or tied to a particular domain, depending on the level of the work domain representation which is the object-domain of the activity.

Second, for compatibility with mental strategy descriptions and analysis, the description of the activity must be transformed into a representation in terms of information or decision processes connecting “states of knowledge.”

These two aspects of work analysis is described in the following sections

2. Activity Analysis in Domain Terms

Since the classes and terms of the work domain representation are imported from the relevant domain related professions, this will also be the case for the sub-set relevant for a particular situation. However, also classes and terms related to the state of affairs and the activities of staff in the situations considered will be necessary. In general, these concepts will be imported from the vocabulary which have evolved from the profession actually involved in the work and will form a special work language which is particular for the profession and the organization (team). Only some very general classes of situations can be suggested as follows: The task can have its origin in an unstable work domain in which control actions are necessary to *maintain* a stable condition, or actions are needed to *adjust system state* in response to changes. Such need for adjustment can be due to changes in the environmental coupling propagating downward through the system or effects of physical changes such as faults or introduction of new tools, propagating upwards through the means-ends map.

Generic Classes of Activities to be expressed in Domain Specific Terms:

- Explore Options in Domain
- Maintain State of Affairs in Response to internal Disturbances
- Respond to External Changes of Requirements
- Maintain State of Affairs in Response to external Request
- Change State of Affairs in Response to Change of Situations and Goals.

The description of activities in terms of decision processes which is discussed in the following section, it is important to realize, that complex activities normally are punctuated by more or less standardized “states of knowledge” serving as key notes used for communication with cooperators or labels for memorizing situations. Such labels are listed in the table below:

Classes of “states of knowledge” to be expressed in Domain Specific Terms:

- observed data;
- actual state of affairs in the domain;
- goal to pursue;
- target state to seek;
- task to perform;
- procedure to use;
- action to perform;

So far, task requirements are only expressed in work domain terms such as ‘operation’ of a patient in a hospital, an attack mission by a fighter pilot, production planning, etc. In order to be able to determine the information requirements of a task and to relate task requirement to cognitive resources of the agent, it is necessary also to *analyze activity in terms of decision making functions*.

3. Activity Analysis in Decision Making Terms

In order to further decrease the field of relevant options in behaviour likely to be chosen by an agent, it is necessary to shift the language of description from terms of the work domain to terms comparable with the individual decision maker's resources and preferences. This means, that the activity elements defined above must be described in information processing terms to create an interface between the overt activity and the possible mental strategies and processes that will serve the work domain requirements. The delimitation of the degrees of freedom will be expressed by specification of the *decision tasks* in information processing functions terms which are necessary to interrelate the various states of knowledge expressed with reference to the state of affairs of the work domain. Categories of the taxonomy in this facet of description are decision functions such as information retrieval, situation analysis and diagnosis, resource evaluation and selection, prognosis and prediction, goal evaluation, priority judgement, planning, execution and monitoring.

The explicit definition of the constraints defining these decision functions does not imply actual application of the corresponding rational decision making strategies. The decision functions only define the boundary within which the behaviour of the individual agents, including computers, can be found. The individual decision functions implied in a decision task will not, in general, be clearly separated; their mutual relationships will depend on the work domain and the task situation, as illustrated in figure 21. This complicates the analysis, but will not change the need for a clear taxonomy. Formulation of a generic set of decision tasks will facilitate the design and evaluation of decision support systems significantly because a proper field study in many cases can be replaced by a structures interview of the target agents. The choice of decision support strategy will be determined by the type of decision task, not the particular details of the task.

Analysis

The representation is built on data collected during the analysis of the decision situations in domain terms, supplemented with verbal protocols, observations and structured interviews. As it was the case for analysis in domain terms, strategies and subjective criteria for choice can only be identified in particular processes, not for general situations. On the other hand, generalization cannot be done in terms of a typical decision task process, only in terms of the requirements of prototypical decision tasks represented in terms of the relevant set of useful strategies.

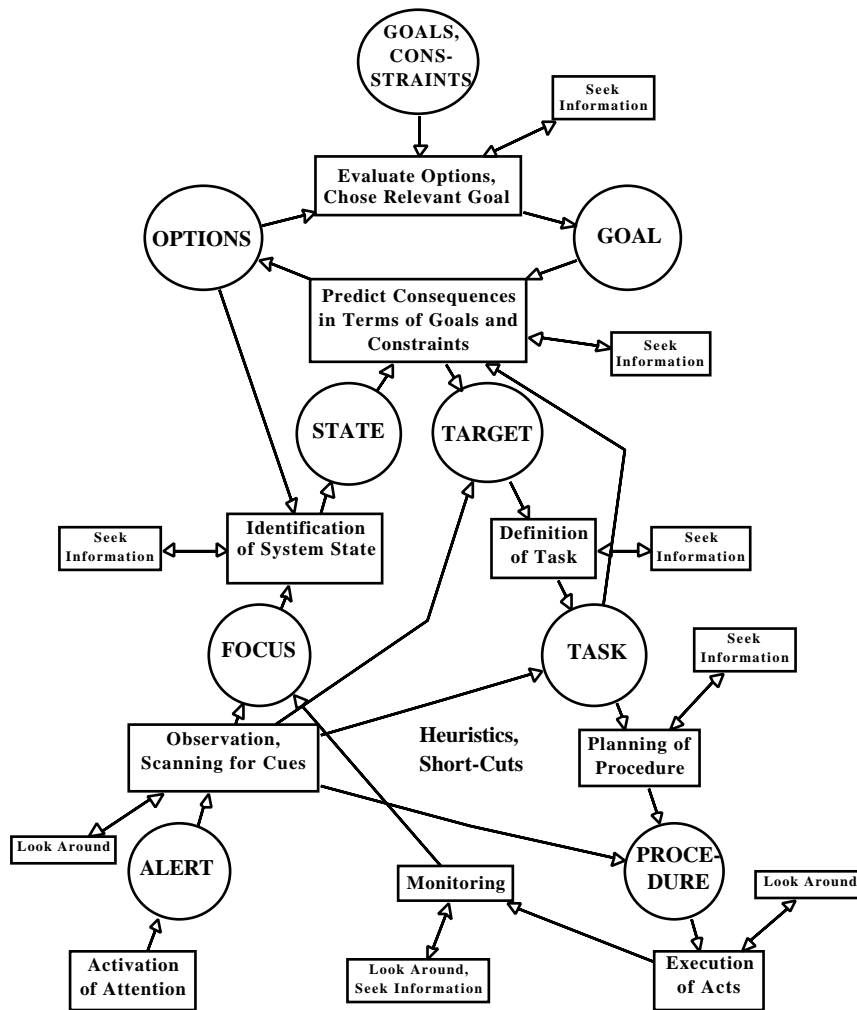


Figure 21. The figure illustrates the sequence of basic information processes in a decision task together with a number of heuristic short-cut paths. It serves to identify a number of basically different decision functions such as situation analysis, value judgement, goal evaluation, and planning, which are used to connect different “states of knowledge” with respect to the activity in the work domain. Such “states of knowledge” are used as standard key notes for exchange of information between basically different decision and information processes and for communication between cooperating agents.

Application

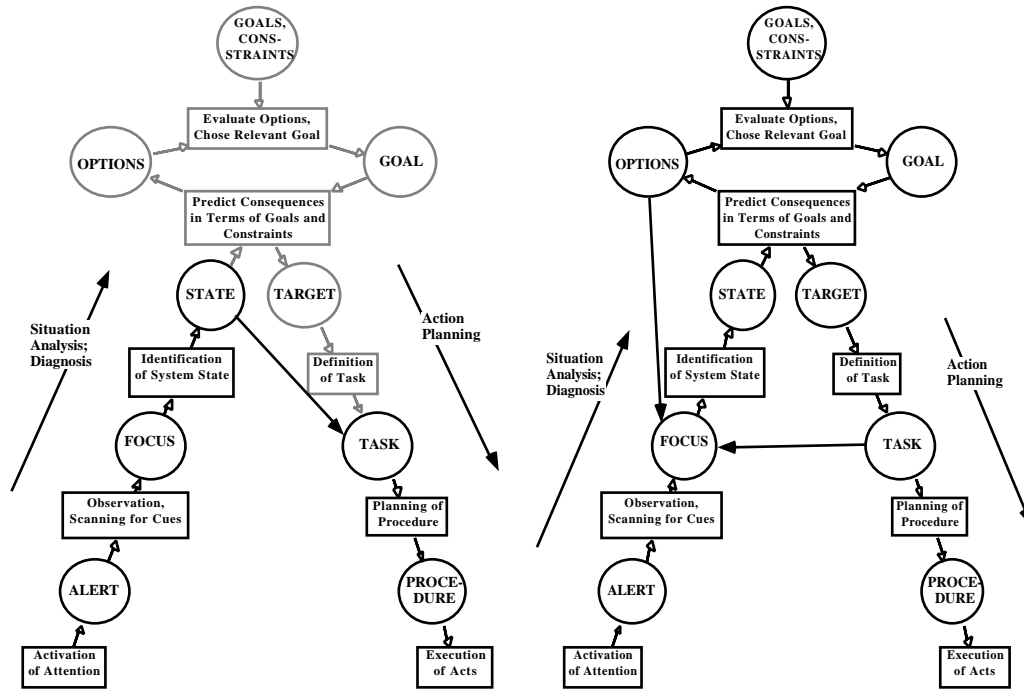
This level of analysis will describe the prototypical decision situations in terms of the decision processes as defined in the decision ladder, the possible mental strategies for the relevant decision task elements, their information requirements, and the subjective process criteria which the individual agent can use for the actual choice. In addition, the decision ladder is useful to illustrate the allocation of roles to the individual cooperating agents to specify further the information need for the individual agent.

Information System. The information gained in this analysis will identify the conceptual relations and the retrieval attributes which should be attached to the individual knowledge items of the knowledge base of an information system together with the effective retrieval strategies of a user.

Classes and Terminology

Generic classes of Decision Subtasks to be expressed in domain specific Terms:

- Data Collection, Observation
- Identification and situation analysis, diagnosis;
- Evaluation and priority judgement;
- Decision and choice;
- Planning



Diagnostic Task for Repair and for Control

Figure 22 illustrates an analysis in the decision task dimension in terms of information processing. The figure serves to identify the difference between the diagnostic task in a repair situation and for control planning. In the first case, the diagnostic and the planning task are well separated, because the task always will be to replace the failed component or part and, therefore, the diagnostic task invariably will be to *locate in physical space* the failed part. In the second case, systems control during failed conditions has conflicting goals such as to maintain system production, protect equipment from damage, or to avoid injury to people or contamination of environment. In this case, there is a circular relationship between the diagnosis of the situation, the goal to pursue and the alternative means for action. In other words, the diagnostic task and action planning cannot be separated.

Discussion

An alternative classification scheme which is compatible with the present framework has been proposed by Rouse et al. (1984).

EXECUTION AND MONITORING

1. IMPLEMENTATION OF PLAN
2. OBSERVATION OF CONSEQUENCES
3. EVALUATION OF DEVIATIONS FROM EXPECTATIONS
4. SELECTION BETWEEN ACCEPTANCE AND REJECTION

SITUATION ASSESSMENT: INFORMATION SEEKING

5. GENERATION/IDENTIFICATION OF ALTERNATIVE INFORMATION SOURCES
6. EVALUATION OF ALTERNATIVE INFORMATION SOURCES
7. SELECTION AMONG ALTERNATIVE INFORMATION SOURCES

SITUATION ASSESSMENT: EXPLANATION

8. GENERATION OF ALTERNATIVE EXPLANATIONS
9. EVALUATION OF ALTERNATIVE EXPLANATIONS
10. SELECTION AMONG ALTERNATIVE EXPLANATIONS

PLANNING AND COMMITMENT

11. GENERATION OF ALTERNATIVE COURSES OF ACTION
12. EVALUATION OF ALTERNATIVE COURSES OF ACTION
13. SELECTION AMONG ALTERNATIVE COURSES OF ACTION

Table 23. Decision function categories suggested by Rouse (1984) for design of decision support systems. Note, that the classes are closely related to those of the decision ladder in figure 21. The major difference being a decomposition into elementary processes which, in the present framework, would be done during the definition of the mental strategies, because some of the elementary processes are only needed in case of new situations.

4. Information Processing Strategies

Any one of the prototypical decision functions can be implemented by means of several different information processing strategies, which pose different requirements with respect to mental models, information, and processing capacity. Shifts in strategy, therefore, can be a very efficient way to circumvent resource limitations in an actual task.

Description

An analysis of the cognitive activity is therefore necessary to identify those information processing strategies which are effective for different phases of the decision sequence in order to identify the required data, mental models, and processing capacities. It is generally found that a given cognitive task can be solved by several different strategies, varying widely in their requirements as to the kind of mental model and the type or amount of observations required. (See, for instance, for concept formation: Bruner et al., 1956; for trouble shooting: Rasmussen et al., 1974; and for bibliographic search: Pejtersen, 1979). An analysis of the task is therefore important in order to identify the different strategies which may serve the different phases of the decision sequence, and to select those which are considered effective and reliable.

An important part of the analysis is the identification of the general resource requirements of the strategies in terms of the required input information, background knowledge (mental model), and processing capacity, etc., and the consequences of errors.

Examples of Mental Strategies

Diagnostic Strategies in Trouble-shooting

Different diagnostic strategies applicable for trouble shooting in technical systems have been identified from analysis of verbal protocols (Rasmussen and Jensen, 1974). In general, the diagnostic task is a search to identify a change from normal operation in terms that can refer the repairman to the location of the fault. Such a diagnostic search can be performed in two basically different ways. A set of observations representing the abnormal state of the system - a set of symptoms - can be used as a search template to find a matching set in a library of symptoms related to different abnormal system conditions. This kind of search will be called *symptomatic search*. On the other hand, the search can be performed in the system with reference to a template representing normal function. The change will then be found as a mismatch and identified by its location in the system. Consequently, this kind of search strategy can be called *topographic search*. The topographic search is performed as a good/bad mapping of the system. Symptomatic search is a search through a library of abnormal data sets, "symptoms," to find the set that matches the actual observed pattern of system behavior. The symptomatic search can be a parallel, data-driven *pattern recognition*, or a sequential *decision table search*. Furthermore, reference patterns can be generated on-line by modification of a functional model in

correspondence with a hypothetical disturbance, and the strategy can then be called *search by hypothesis and test*. The important issue here is that different possible strategies for the same task may have very different resource requirements, for instance in terms of data, knowledge of basic system functions, processing and memory capacity. Shifts in strategy, therefore, will be very effective for obtaining a suitable resource/demand match, and the complexity and variance of the trajectories through the work space observed in actual task performance generally will be caused by attempts to match the immediate task requirements to the available knowledge and processing capacity by frequent shifts in strategy.

Strategies for Information Retrieval in Libraries

The same feature has been found from analysis of actual user-librarian conversations in public libraries. In the task to identify books that will match a user's needs, several different strategies were identified which show the same great difference in their resource requirements (Pejtersen, 1979). A *bibliographical search* identifies the proper documents by author and title. This information will, however, frequently not be known in advance. In this case, *analytical search* can be used to explore systematically the dimensions of the user's needs and to compare them with the relevant aspects of the available books. However, the user's needs may not be explicitly formulated and then *search by analogy* may be a useful strategy. In this case, a librarian, for instance, can explore the users' needs by asking for information about the users' previous reading, to be able to find 'something similar.' Prototypes thus identified are analyzed to identify search terms for new books. Frequently, it turns out that librarians frequently have developed *empirical strategies* representing effective shortcuts, being based on a prototypical classification of users and books by the librarian. Titles to suggest are selected from correlation experienced between user categories and typical reading habits. Users are classified according to a number of informal features such as visual appearance, verbal style, dress, age, etc., in addition to their expressed wishes, and books are classed in simple genre classes. Finally, a user of a library may have a need which is so ambiguous that specification of a search template is evaded and, instead, the content of a shelf or a database is scanned in a *browsing strategy* in order to experience a match with the intuitively present need.

It will be seen that the strategies available to users in both work domains are very different with respect to the kind and amount of observations and knowledge they require as well as to the necessary mental processing capacity. Consequently, shifts in strategy during work will be a very effective way to compensate for lack of resources. For system design this is a very important point since user acceptance very likely will be related to the freedom to choose strategy according to subjective process criteria (rather than to objective goals or product criteria) without losing support by the system.

Application

The results will be the basis for matching these requirements with the resource characteristics of the designer, the computer, and the ultimate user for the planning of their roles in the interactive decision task.

Information system. In addition, guides can be obtained for selection of suitable support of the mental models required in terms of information content of suitable display formats and the relevant levels of data integration. It is a design objective to match the information *content* of displays to the mental model which will be effective for the task and to choose the *form* of the displays in a way which will guide users' subjective preferences in that direction. As mentioned, the various strategies will have very specific needs with respect to type of useful data, useful mental models, etc. In 'intelligent' decision support systems it should be possible to let a computer analyze the user queries in order to identify the strategy a user is trying to apply and then to supply the required support in displays and messages of the proper form.

The requirement that the interface design must guide users to form effective mental models and adopt proper strategies presupposes that it is possible to characterize different strategies with respect to features that are related to users' subjective criteria for choosing a given strategy as the basis for their performance. The criteria for this choice will frequently depend on properties of the information process itself, rather than its result. This requires an analysis in the borderline between operations research and psychology, and represents an area where a combination of laboratory experiments and generalizations from various real life analysis can be very fruitful. Some results are available, indicating important process criteria, such as cognitive strain, load on short-term memory, cost of observation, time available, data and resource limitations in general, cost of mistakes, etc. (Bruner et al., 1956; Rasmussen et al., 1974). More research in this area is needed. Interface design and computer support of decision making will only be successful if based on a proper knowledge of the performance criteria and subjective preferences the user will apply for the choice of strategy in the actual situation.

Classes and Terminology of Mental Strategies

The different strategies can be implemented by several different sets of *elementary information processes*, which in different combinations can be used to form the different strategies:

Elementary Information Processes

- Association
- Induction
- Deduction
- Hypothetico-Deduction
- Search
- Comparison and Choice

- Evaluation

In conclusion, it is necessary to characterize the decision tasks in terms of mental strategies which *can* be applied in actual work. It is important to be able to characterize the strategies observed in terms which make it possible to compare the individual strategies with the cognitive resources, i.e., competence and processing capacity, as well as with the subjective preferences of individual agents.

The description of strategies should be in terms of:

- * the relevant set of elementary information processes applied
- * the type of mental model necessary for applying the information processes
- * the actual interpretation of the observations applied during the strategy
- * value features which can be related to the subjective preferences of a subject in a particular situation, such as:
 - Resource requirement: Time, information or physical / mental capability
 - Specific to certain task situation or widely applicable
 - Sensitivity to disturbances
 - etc.

As an example set, consider the strategies identified in trouble shooting and library search and shown in table 23.

Generic Strategies

Proposal: Can we formulate higher generic classes of strategies such as:

analytical, model-based strategies

empirical categorization-based strategies

empirical recognition driven strategies

or: will such classes correlate with the cognitive control levels?

Information Processes	Mental model	Interpretation
Trouble shooting		
Recognition	Compare Judge	Pattern template Signs
Decision table search	Search Compare	Library of symptom patterns Signs
Topographic search.	Search Match Judge	Structure map Normal reference patterns Signs
Search by hypothesis and test.	Induction, Deduction Compare, Judge	Declarative, structural model, causal relationships Symbols
Library search		
Bibliographical search	Search Compare	Topography of tools Symbols and Signs
Analytical search	Induction, Deduction Compare, Judge	Structural, semantic network of users' universe Symbols
Search by analogy	Search Match Judge	Library of symptom patterns Signs
Empirical strategies	Categorize Match	Library of symptom patterns Signs
Browsing strategy	Search Match	Tacit template Signs

Table 23: Strategies in process control and libraries.

Organizational Analysis

Closed and Open System Perspectives

In accordance with the conception of the system of work as an adaptive system, organizational analysis of work will basically apply an open systems perspective.

An open systems perspective is by now the prevalent paradigm in organizational theory where it has been explored and developed since the paradigmatic shift was inaugurated by the work of Woodward (1965), Thompson (1967) and others in the 1960's.

The paradigmatic shift to an open systems perspective has been incited by the concurrent emergence of dynamic business markets and the accompanying efforts of enterprises and offices to develop organizational capabilities to handle the taxing demands of dynamic environments. Of course, organizations always have been open systems in the sense that they exchange energy, materials, information etc. with their environments. But in the analysis of conventional mass-production enterprises in placid and predictable environments a cautious and guarded abstraction from the 'open' nature of the system is legitimate and provides valuable insight, in so far as the inevitable manifestations of the 'openness' of the system (e.g., disturbances) can be interpreted as local and temporary deviations from plan.

During stable periods which permit long term planning and supply of standardized goods to a general market, a system, i.e., a company or an organization, can be 'decoupled' from the variability of the environment by stores and inventories which serve as buffers. In this situation, there is a significant difference in the time scale of the dynamics within the system (internal disturbances require fast responses) and in the coupling to the environment which is typical of having long time constants (planning periods from one to several years). For more detailed discussion of the properties of the work domain viewed as a dynamical functional structure, see the discussion of the work domain dimension of the taxonomy, p. ??.

The emerging, highly dynamic business environments, however, makes an complete inversion of perspective mandatory. Instead of conceiving the system of work as a closed and stable system, subject to local and temporary disturbances, a system of work should be conceived of as an open system that reduces complexity and uncertainty by "local and temporary closures" (Gerson and Star, 1986).

In analysis of systems of work exposed to the complexity and pace of change of modern markets, the closed system perspective should be subordinate to the open systems perspective. That is, stable and formalized organizational structures and processes are less characteristic than flexible and rapidly changing patterns.

The typical work domain will be rather loosely coupled, that is, only in special cases (such as for example assembly line work) will the requirements of the work domain be able to pace the agents directly in a coordinated way. In most cases, communication among agents is necessary for coordination. In the present context, *organization* does not

refer to stable groups of people as seen in organizational charts, but to the relational structure necessary to coordinate the work activities of several individuals. In contrast to the *formal organization* which reflects the allocation of economic and legal responsibility to groups and individuals, the *actual organization* of work and social relations reflects very dynamic relationships.

Work Organization and Social Organization Perspectives

In the present context, it is important to develop a framework for the discussion of the organizational and management aspects which, on one hand, is compatible with the cognitive, information processing point of view and, consequently, can be used to support information system design and, on the other hand, maps well onto the frameworks available from social and organizational sciences. The following discussion is intended for this purpose.

The discussion by Ashby (1962) of the nature of organization and self-organization is very relevant in this context. According to Ashby, the core of the concept of organization is that of ‘conditionality.’

“As soon as the relation between two entities A and B becomes conditional on C’s value or state then a necessary component of “organization” is present. Thus the theory of organization is partly co-extensive with the theory of functions of more than one variable.” (Ashby’s emphasis).

He goes on:

“The converse of ‘conditional on’ is ‘not conditional on’, so the converse of ‘organization’ must therefore be, as the mathematical theory shows as clearly, the concept of ‘reducibility’. (It is also called separability).”

This definition of organization is very compatible with the definition underlying the use of communication analysis used below for the identification of the actual work organization.

Ashby continues:

“The treatment of ‘conditionality’ [...] makes us realize that the essential idea is that there is first a product space - that of *possibilities* - within which some subset of points indicates the actualities. This way of looking at ‘conditionality’ makes us realize that it is related to that of ‘communication’; and it is, of course, quite plausible that we should define parts as being ‘organized’ when ‘communication’ (in some general sense) occurs between them. [...] Thus the presence of ‘organization’ between variables is equivalent to the existence of a *constraint* in the product-space of possibilities. I stress this point because while, in the past, biologists have tended to think of the organization as something extra, something *added* to the elementary variables, the modern theory, based on the logic of communication, regards organization as a restriction, a constraint.”

Another point, raised by Ashby, is that of ‘good’ and ‘bad’ organization. His conclusion, which supports the definition of the dynamic work organization in the previous section, is the following:

“*there is no such thing as a good organization in any absolute sense. Always it is relative; and an organization that is good in one context or under one criterion may be bad under another.*”

In conclusion, if the organization is allowed to adapt to the requirements of a changing environment, a very flexible and variate work organization will evolve.

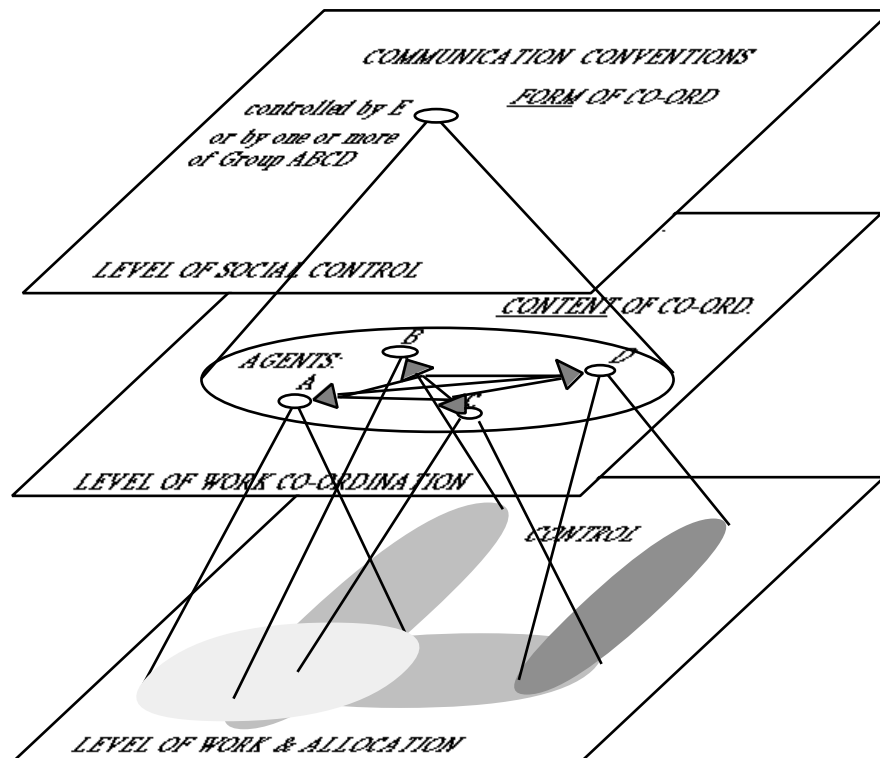


Figure 24 illustrates four agents or decision makers each allocated particular, but overlapping 'activity windows' giving access to a part of the overall work domain. The concerted action within this, normally rather loosely coupled, work domain requires inter-agent coordination and communication. The structure of the communication net and *content* of the communication and, therefore, the actual work organization, is determined by the control requirements of the work domain. The social organization, in contrast, is determined by the conventions chosen for the *form* of the communication, which depends on the 'management school' or 'culture.' This, in turn determines whether the decision making at the level of social control involves another agent E or one particular agent of the group ABCD in a hierarchical organization, or them all, in a democratic coordination process.

Analytical Perspectives

As a social system, the system of work is an extremely complex organizational phenomenon involving multitude forms of social interaction. To cope with this complexity, it is useful to distinguish (1) the system of work as a functional system from (2) the social system of work as an arena for human actors. This distinction defines two basic perspectives on the social system of work: a 'work organization' perspective and a 'social organization' perspective.

Following this point of view, we will have to consider organizational aspects at two different levels of analysis: The *work organization*, will be determined by the control requirements of the work domain and by the role configuration architecture chosen by or imposed on a group of cooperators. The necessary coordination of the cooperating individuals following from this architecture will specify the *content* of communication. On the other hand, the architecture of the *social organization* will depend very much on the *form* of the communication, i.e., on the conventions and constraints chosen for this communication, see figure 24.

In other words, a particular division of activities and, consequently, work organization will evolve for each situation guided by the competence of the actors and the 'technology' of the work domain and will be determining for the content of inter-agent communication. The social interaction among the agents, on the other hand depends on the form of the communication which in turn depend on the 'management style' or coordination strategy adopted. The work organization is determined by the work domain and the role configuration, while the social organization is evolving from the general human values guiding the coordination effort.

5. Work Organization

The work organization perspective conceives of the system of work as a *functional system of cooperative relations*. The focus of the work organization perspective is the system of work as an *instrument* facilitating the interaction of the functional requirements of the environment with the technical and cognitive resources, i.e., the system of work is a complex network of means-ends relations. The basic many-to-many relationship in this network and its loose coupling is the basic source of the need for human intervention in order to remove ambiguity and to control the functional state. In this way, the perspective is congruent with the ‘rational systems’ perspective as defined by Scott: “From the standpoint of the rational system perspective, the behavior of organizations is viewed as actions performed by purposeful and coordinated agents.” (Scott, 1987).

The work organization perspective conceives of the system of work as a rational system in the sense that it, by and large, is *functional* to the environment by producing a product, providing a service, or whatever, under the specific conditions and constraints characterizing the environment. As an open, rational system the work organization is conceived of as permeated by its environment.

Forms of Cooperative Work

The configuration and allocation of decision roles can be specified in absolute terms (depending on topographic location, on access to information, on regulations such as union agreements) and in terms of criteria governing dynamic allocation by the agents themselves (such as preference for particular social patterns, mutual concern about equal work load, etc.). The classes and terms to apply within this dimension should be compatible with the ‘cognitive sociology’ point of view presently emerging in order to facilitate the use of their methods of analysis. On the other hand, as mentioned, it is important to have a theoretical framework which relates to the cognitive engineering perspective of systems design.

In the discussion of forms of cooperative work we can, from this point of view, distinguish different perspectives:

1) One is the partitioning of the sum of total set of activities in the system into activities which can be allocated to or chosen by an individual actor. This partitioning can be described from different points of view. One is, *what is partitioned*, i.e., what kind of representation is used for partitioning. This choice will result in different *role configurations*.

2) Furthermore, the choice of boundaries between the activities which are adopted by or allocated to different individuals can be guided by several different criteria, leading to a discussion of the different *task allocation criteria*.

In this discussion, we have only considered activities in the context of the work requirements, from a functional point of view. Another perspective as perceived by the *individual person* is necessary to analyze other factors, such as, e.g., work load

3) This perspective leads to a consideration of *combination of activities*, i.e., the way different elementary activities are linked for the individual actor. In the previous sections of the taxonomy, we have considered activities in terms of functional elements without reference to *who* is taken care of the function. When we turn to the role of individuals and groups, however, we have to aggregate the individual functional elements, i.e., the work activities, into *tasks* which represents the overlapping and interleaved activities which an actor will cope with in *a particular situation*, irrespective of whether they are directly and functionally connected.

4) Finally, we have to consider the aggregated activities of an individual *across time*, to evaluate the combination of competences a particular person should bring to work. The tasks and activities which are adopted by an individual will go together into a *job design* which also will be subject to certain constraints to consider for the task allocation, in particular with reference to the competence of the actor and the general ‘quality of working life.’

In the following sections, we will have a closer look at these aspects of cooperative work.

1. Role Configuration Architecture

The first level is defined by the question: *What* is distributed in a cooperative work setting. Basically, cooperative work relations are established because of the limited capabilities of single human individuals, that is, because there are certain limits to their physical resources, to their professional competence, and to their commitment. From a functional, work requirements point of view, role configuration can be based on the simple fact that people have limited capacity, that they cannot be at more than one place at a time, that their professional competence cover only certain functions, that they are specially equipped for certain work processes, etc. This leads to the following first attempt to formulate the basis for the role configuration to expect in a dynamic work organization. It is important to remember, that several configuration architectures will compete and the governing one will change with time and work conditions. The following list is only meant to be illustrative:

The allocation of roles to individual members of a work team can be made in different ways, resulting in different architectures of the work organization:

Individual Work

An individual agent can be assigned to cope with the entire problem space in consideration for a particular work scenario, irrespective of the decision functions and information processes the work implies. This is often the case for experimental work which, for this reason, will have a very special character.

Cooperative Work

Normally, however, the effort of multiple people is a prerequisite to accomplishing the objective of the activity.

Collective Work

In some cases, a group of people acts together, pooling their resources and knowledge in a kind of collective activity. This mode of cooperative work can be called *augmentative cooperation*, i.e., multiple agents are allocated to the same task or type of task so as to resolve limitations in anthropometric, physiological, or information processing capacity in cases where either requirements are too great and combined effort is necessary (activity in separate places, lifting heavy load), or a task cannot be decomposed to sequential elements, therefore simultaneous, parallel activity is necessary of a group of agents with similar tasks (performing musical concert). Another example can be the group problem solving during disturbances in a control room of a process plant when no structured cooperation is found, and the ‘collective mind’ of the staff seek to find a creative solution.

This form of cooperation simply *augments* the mechanical and information processing capacities of human individuals and thus enable a cooperating ensemble of workers to accomplish a task that would have been infeasible for the workers individually.

Augmentative cooperation will typically require real-time communication. This is not the case under all circumstances, however. In the typical case of augmentative cooperation, cooperation resolves demand resource conflicts at the physical process level and the required communication is determined by the intrinsic coupling at this level. The required synchronized actions by the human agents can be implemented in different ways:

- physical coupling through work content (movement of assembly line),
- orders (vertical communication) from coordinator (musical conductor),
- mutual (horizontal) communication among actors (work song) for timing.

On the other hand, certain batch processes may not need synchronization, at the process level, only the output should be available to certain times and in volumes. In that case, coordinating coupling is only necessary at the general function level (production of documents in a typing office, production of components for assembly shop). In that case, coordination will normally be accomplished by orders or schedules from coordinator, or by mutual communication for load sharing. This discussion points back to the intrinsic coupling within the work domain discussed in section 1.1.

Augmentative cooperation is being eroded when technology is introduced in the sense that the need for cooperation to compensate for resource limitations can be removed by ‘augmentation’ of the capabilities of the individual.

In an organization of actors cooperating in this way, role configuration can be described in different kinds of representation:

Strictly speaking, augmentative cooperation can involve ‘collective’ activities if work domain and processes are in common for a group, or domain based allocation if agents are working on different topics in parallel. Note, that in this case it will frequently also be

with different tools and competence, i.e., cooperation is augmentative as well as integrative, the distinctions are not orthogonal.

Distributed Cooperative Work

In general, however, cooperative work is done in a distributed manner, i.e., involving relatively autonomous decision makers.

In general, cooperative work serves what can be called *integrative* cooperation. This distinction focuses on the availability of physical tools and mental techniques. The development of effective tools and techniques (mechanization and training) leads to increasing differentiation and specialization of the role of the individual agent, which in turn leads to an increasing need for cooperation in terms of integration (combination, coordination, scheduling etc.) of the *the activities* of multiple specialized workers devoted to the operation of different specialized tools, techniques, or routines. The differentiation of work requires the concerted cooperation of multiple workers representing the different specialities. The resources of the individual become more effective, but narrow because of the inclination to require effective use of specialized tools (expensive machinery and skilled experts) until automation makes it possible to remove routine functions from human work.

Another version of distributed cooperative work is the *balance oriented architecture*, i.e., agents are allocated in surplus to a task so as to counterbalance biases. This form of cooperative work facilitates the application of multiple problem solving *strategies and heuristics* to a given problem so as to serve the function of balancing the individual biases ('bias discount', in the words of Cyert and March (1963)). By critically assessing the discretionary reasoning of fellow workers and counterbalance perceived biases, cooperating individuals may, as an ensemble, arrive at relatively balanced and objective decisions in complex environments.

Domain oriented architecture

In this case, the individual actor takes care of different parts of the functional work domain, the activity of the individual agent is related to different object domains in the work space or specific perspectives. This form of cooperative work facilitates the application of multiple *perspectives* on a given problem so as to match the multifarious nature of the work environment. See figure 25 & 26 for an example.

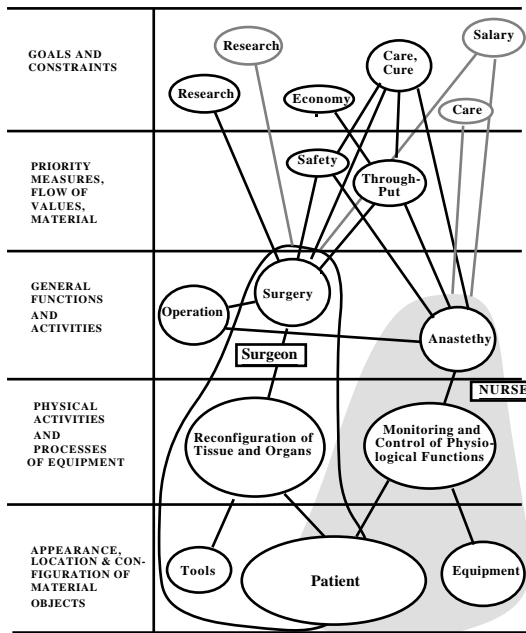
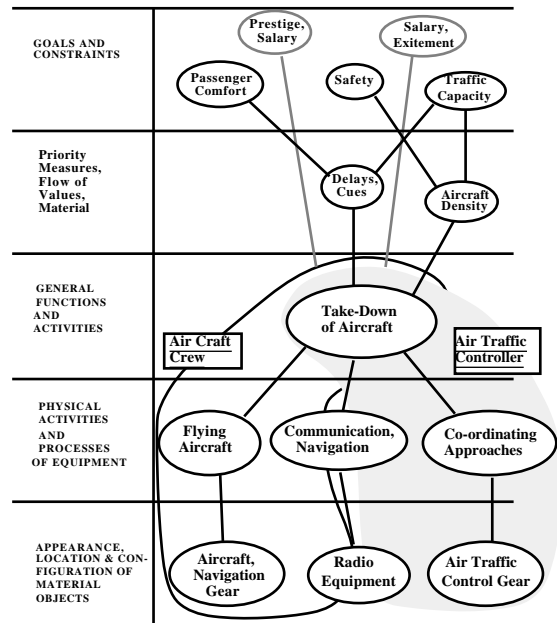


Figure 25. The figure illustrates one mode of cooperative work. Two agents are serving different parts, surgery and anesthetics, of the overall function of operating a patient. In the situation shown, the role allocation depends on the requirement for simultaneous, parallel activity and for different professional background and skills. They work on the same object, the patient, and some of the necessary information exchange will be through the visible state of affairs around and including the patient. However, additional communication will be necessary for coordination, defined entirely by the work requirements and the cooperator's intentions. Implicitly, the activities will be governed by a complex network of priority measures, goals and subjective motives of work. These measures will, however, only be 'activated' and considered explicitly in planning situations or when special difficulties are met.

Figure 26. The figure illustrates another mode of cooperative work. The two agents involved are cooperating in the same general function, each allocated a different work process based on different equipment. In the operation of figure 25, the spatial and temporal coordination was largely taken care of by the common physical environment and coordination was focused on higher semantic levels. In the present task, coordination is very much focused on the temporal spatial characteristics of a domain which is not directly visible to both operators. The conclusion is that the need for communication, as presented by the work space, depend very much upon the particular work situation.



The work space is often a complex of multiple, ontologically distinct object domains. This multiplicity of distinct object domains must be matched by a multiplicity of perspectives on the part of the cooperating makers so as to enable the apprehension of the diverse and contradictory aspects of the work space as a whole. The crux of this form of cooperative work, then, is to interrelate and compile the partial perspectives. A very typical example is the one faced in any design task, see figure 27.

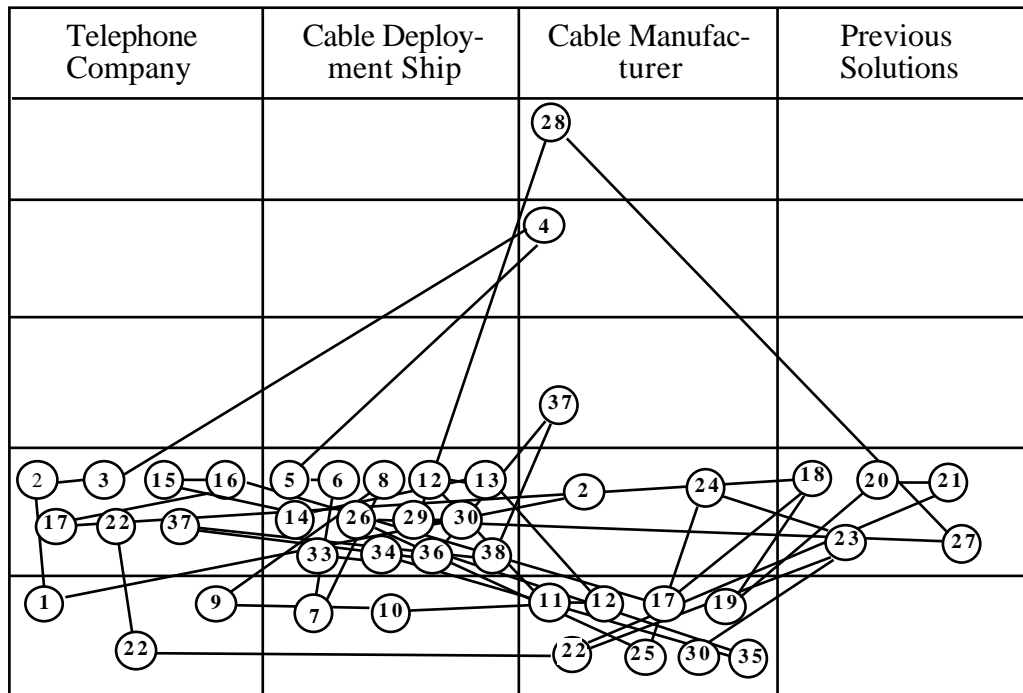


Figure 27. In many work situations, several different work domains must be considered and the task will be to establish the conditions under which the effect of decisions are acceptable in the various domains. The figure shows the trajectory in the work domain of a design task: the design of a cable joint for optic fiber telephone cables. In this case, the object of design belongs to different ‘object worlds:’ it is a joint in a telephone cable, it is part of an assembly task under rough sea conditions, and, finally, it is an object to be manufactured by the equipment of the cable manufacturer. The figure is only meant to be illustrative. For details, see Rasmussen, 1988.

Communication between agents allocated different domains will depend very much on the opportunity an agent has to be familiar with the domain of the cooperators. Whether the domains are part of the normal environment in, e.g., the same company, or they are belonging to different contexts which are only occasionally in contact, e.g., belonging to a product designer and contiguous client. The characteristics of a perspective, however, should not be phrased in terms of rules but, more basically, in terms of means and ends and their potential relations.

In real world settings, the different cooperative architectures are combined in specific configurations determined by the specific nature and requirements of the work environment. This form of cooperative work can be further specialized in two different architectures:

Process oriented architecture

Here, agents are allocated only a particular selection of information processes for which they have specialized tools and techniques.

Function oriented architecture.

For this architecture, selected functions are allocated to agents, such as analysis and diagnosis, goal setting, planning, and execution, for which they are specialized or for which they have access to the information needed.

2. Criteria For Division Of Work

Within the above architectures, a distribution of activities can be chosen by or allocated to different members of the cooperating ensemble with reference to different criteria: which worker is to do what, where, when, level of quality? How should tasks be combined into job designs?

In general, several decision makers will have to cooperate in the control of the system represented by the problem space, and decision making at a level above the primary decision makers can be necessary for coordination of decision making in order to assign decision functions and workload depending on the changing conditions and requirements of the system (see figure 24). This meta-level is necessary except in stable systems in which control decisions can be entirely and deterministically data driven and allocated to fixed roles (in which case they hardly can be characterized as decision makers but instead are merely 'automatic' controllers). In this case they have no degrees of freedom, and coupling among them is entirely dependent upon fixed rules and the communication through the work content or primary system function. Normally, however, the control requirements have to be decomposed into sets of tasks which can be handled by cooperating individual agents. Or, in other words, the large number of elementary control tasks are aggregated into task repertoires suited for allocation to the individual agents.

Different principles of allocation will result in different coordination structures. Since control requirements are defined with reference to particular work scenarios and situations, this architecture will change dynamically through time. Within the architecture several, sometimes conflicting, criteria will be determining the decomposition suitable to define the role of individual agents.

In stable systems with a long prehistory, the formal role configuration normally is very closely related to the adopted, frequently hierarchical, organizational structure and the corresponding social status. Very often, this formal structure also poses very strict constraints on the actual work allocation, in particular when strict boundaries between professions are established through union agreements. Such established work allocation criteria can be very counter-productive in a period with rapidly changing technology and, consequently, changing control requirements from the work domain. (See the discussion in the introduction).

For a discussion of the requirements, when changes in system environment and in technological basis has to be considered, some more functional criteria are relevant:

Functional De-coupling

This criterion will serve to minimize the necessary exchange of information among agents. The basic principle will be to identify aggregates which can be separated and controlled as a unit with a minimum of interaction and communication across their boundaries. Within control engineering, special tools are available for decomposition for system decomposition, generally based on matrix manipulation of a connectivity matrix (state-space representation, see for instance Himmelblau, 1973). This technique can be used also to define teams of tightly coupled agents to be organized in groups which are mutually more loosely coupled, see figure 24.

Load-sharing

Frequently, the partitioning of the control structure in several levels along the means-ends dimension of the work domain will be determined from controller capacity considerations. Control at the physical process level require real-time, synchronous information processing, which requires large data processing and communication capacity but, frequently rather simple processing and decision rules. At higher levels, decision problems become more complex and response times will be slower.

Agent Competency

The competence required for different decision tasks is often determining for division of work. In this case, the allocation does not follow the levels of the means-ends hierarchy. This however, can be the case if different acquired skills and decision strategies are the basis for task allocation as for instance in an office management organization, for which the tools and strategies at the various levels are very different.

Allocation for Problem Solving

The information needed to plan and control an activity depend very much on the task allocation, and the difficulty of a decision task depends on the width of the information window. If the window is too narrow and limited to one level of the means-ends hierarchy, improvisation and problem solving will be difficult. The effectiveness and ease with which practical reasoning can serve problem solving depend very much on the opportunity to draw on analogies, to judge whether solutions are reasonable, and to interpret ambiguous messages from other actors from a perception of their motives, opportunities which, in turn, depend entirely on the access to information from several levels of the means-ends hierarchy (see Rasmussen, 1985). This alone is an argument against the effectiveness of hierarchical task allocation in a system which has to survive in a changing environment and to adapt to rapid internal technological change (Drucker, 1988).

Several criteria for task allocation are possible and in any organization the actual, informal task allocation will reflect the immediate strive to match requirements with resources. Shifts in task allocation can be expected to play the same role in de-

mand/resource matching of a group as the shifts in cognitive strategies do for the individual. This, in turn, implies that the architecture of actual distribution of tasks will be very dynamic.

3. Aggregation of Activities into Tasks and Jobs

Aggregation into Tasks

In the previous discussion, the activities have been considered from the functional work requirements points of view, i.e., activities have been considered together in their work relationship. It is, however, also important to structure the description as seen from the individual. A particular individual will, at any point in time, attend different activities which are not functionally related in a time sharing mode. This set of activities, which may only haphazardly be related in time and place, will together shape the actual task, determine the work load, and influence the actual division of labor. In consequence, the division of work will, in addition to the criteria discussed above, depend on factors outside the functional structure of an activity, which should be explicitly considered in any work analysis. Figure 28 gives an example of the potential complexity of the task repertoire seen from the point of view of the individual person.

Aggregation into Jobs

Another aspect which has not been given much weight in the present discussion is the aggregation of activities across time for a particular individual in order to determine the total job content for a proper design of jobs structures and training and education schemes. This is, as important as may be, considered to be outside the aim of the present approach towards design of information systems.

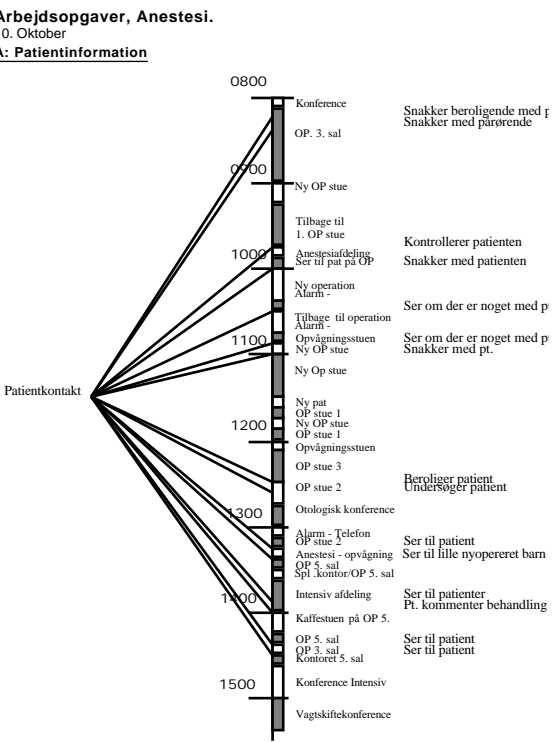
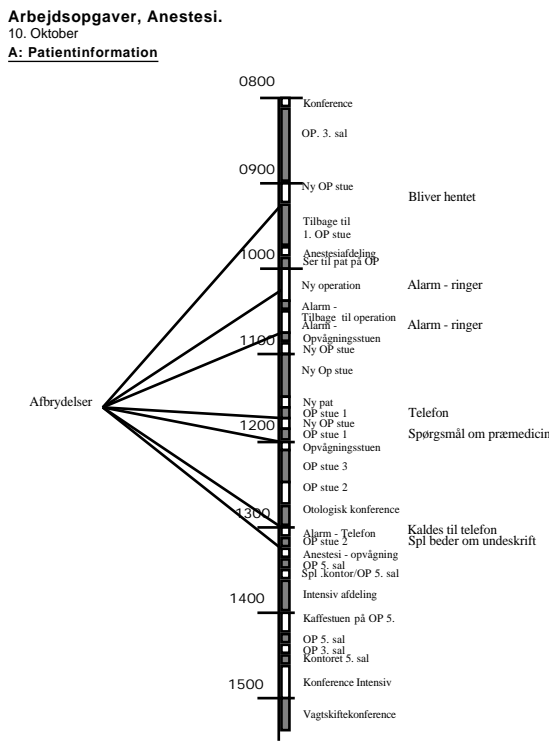
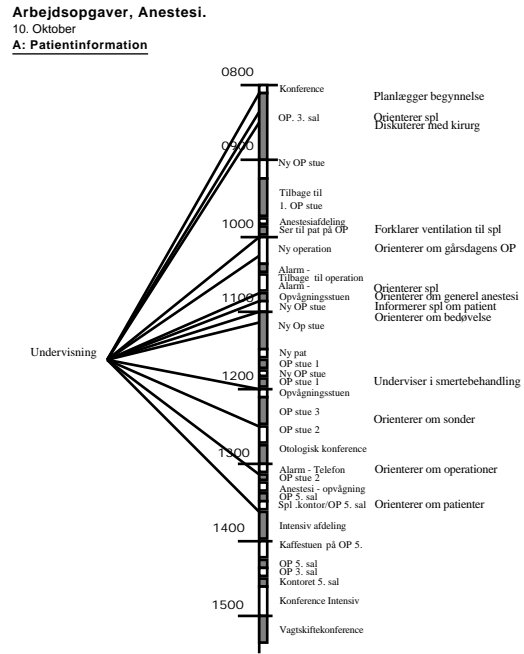
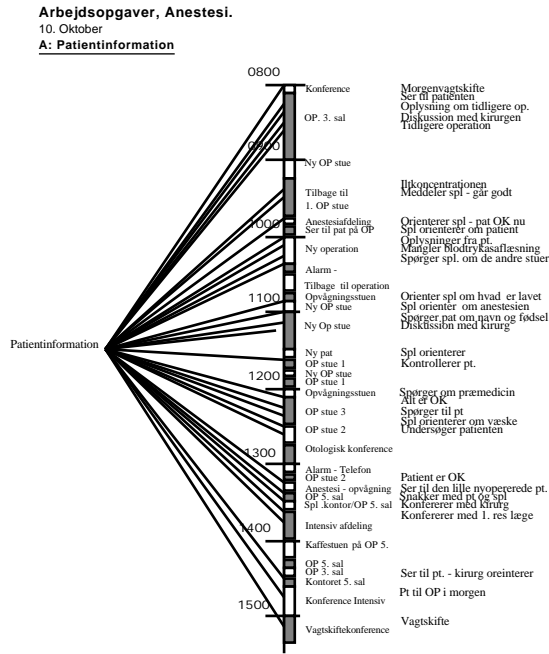


Figure 28 illustrates the activities of a medical doctor during the day (Adopted from Hovde, 1990). It shows the complexity of the activity repertoire seen from the point of view of the individual actor. This point of view is important for e.g., evaluation of work load

Discussion

Organization Theory Point of View

Role configuration principles and task allocation criteria similar to those discussed in the previous paragraphs have been proposed from social science by Thompson. (1967). His presentation of principles and heuristics representing the mechanisms behind the self-organizing evolution of a work organization appears to be a useful source of rules and criteria for the development of a simulation model which will not only be able to simulate organizational behaviour in terms of production-rule based scenario models, but to generate new scenarios by adaptive search to meet higher level performance criteria, derived from Thompson's principles.

A couple of examples will illustrate the close relationship between Thompson's formulations and control considerations:

System interdependence is discussed in terms of:

- Pooled interdependence: Each part is not dependent on others in any direct way, but they support the same whole and are dependent on the same whole.
- Sequential interdependence: output of one part is the input of another.
- Reciprocal interdependence: mutual coupling, e.g., operations and maintenance of an airline.

All organizations have pooled interdependence, more complicated have sequential as well, and the most complex have also reciprocal. Different types of interdependence require different devices for coordination:

- Standardisation: Involves the establishment of routines or rules which constrain the action of each unit or position into paths consistent with those taken by others in the interdependent relationship. (Corresponds to control de-coupling). Typical for pooled interdependence.
- Co-ordination by plan. Involves the establishment of schedules governing the actions of the interdependent units. Better suited for dynamic environment than is standardisation. Typical for sequential interdependence.
- Co-ordination by mutual adjustment. Involves the transmission of new information during the course of action. The more variable and unpredictable the situation, the greater the reliance on mutual adjustment. Typical for reciprocal interdependence.

Which, in turn lead to the following organizational arrangements:

Organisations employing

- standardisation rely on liaison groups to link groups with a rule-making agency (p. 61); (Staff positions).
- sequential interdependence not contained by departmentalisation rely on committees;
- reciprocal interdependence not contained by departmentalisation rely on task forces and project groupings.

Work Psychology Point of View

Allocation of task elements to different categories of employees and to individuals is a central theme of work psychology. Task allocation is discussed from two points of view: 1) the allocation of tasks to individuals, and 2) the coordination of the performance of the individual agents. In analysis of cooperative work, the requirement of collective effort is normally ascribed limited means available for task performance or the presence of organizational constraints. Viewed from the work space structure this implies either resource re-

quirements given from the work domain or organizational requirements which can have different origin, such as competency of persons belonging to different professions or adoption of different coordination policies.

1) *Features Concerning Task Distribution.* The allocation characteristics of cooperative work are discussed by Herbst (1974): either each agent has a specific task or each task can be performed by all agents. It is clear that in the latter case, the flexibility is greater, but so is the load on the manager.

Task characteristics related to the allocation to individuals, as discussed by Herbst (1974) are:

1. Tasks are carried out together or separately, a distinction that relates to the question whether people are working in the same location or not ;
2. Tasks are identical or different, which is related to the question whether cooperation is necessary for pooling resources and/or competency.
3. Tasks are dependent, interdependent, or independent. This question is related to the required coupling and coordination of the activity of the individuals. Finally,
4. Goals can be shared, independent, or unreciprocated. This distinction is related to the question whether there exist a coupling between activities at a higher level in the means-ends network. In general, the concept of goal is not very well defined, it can be formulated at several levels in the means-ends hierarchy.

2) *Collective Activity and Models of Activity.* Leontiev (refined by Brushlinskii (1987) and Radzikhovskii (1987)) posits a distinction between activity, action, and operation. Activity is defined by the motive, action is a process submitted to a conscious goal, operations are the means for action, during learning action is transformed into operation, integrating into wider actions. These distinctions lead Leplat to the following categories in the descriptions of collective work: 1. in 'collective activity', motives are shared, in 2. 'co-activity', individuals work together (e.g., in same place, e.g., production manger and security guard), but are guided by different motives, in 3. 'collective action,' the individuals have same general goal (pilot and co-pilot) and, finally, in 4. 'co-action', individuals have different goals (pilot and ground controller) but are sub-ordinate the same general goal. These distinctions are related to task allocation with reference to the coordination requirements in the means-ends network, which could serve to a more consistent definition of the allocation principles than is possible when referring to 'motives', 'goals' and 'general goals.'

In Leplat's discussion (Leplat, 1988) it is explicitly mentioned that allocation is evolutionary: In co-action coordination is concerned with sub-goals which may become automatic, therefore, collective action will grow at the expense of co-activity. In other words, collective action increase in dimension, co-action in number.

The distinctions adopted from the point of view of work psychology are important for evaluation of the work situation seen from the point of view of working and social qualities of the allocation on a work situation. From the point of view of predictive power and for system design, however, they are less effective, and a clear separation of distinctions related to work requirements, to agent resources and competency, and to work coordina-

tion is necessary. A mapping between the concepts useful for work psychology and system design respectively is possible and should be developed.

6. Social Organization and Management

Whereas the work organization perspective conceives the system of work as a purposive instrument performing a function to its environment, the *social organization* perspective conceives of the system of work as a system of social interaction between multiple individuals with *diverging interests and motives*. The focus of the social organization perspective is the system of work as a *coalition* of individuals with partially discordant interests and motives. The social organization perspective corresponds essentially to the 'natural system' perspective on organizations as defined by Scott (1987). In recent years, this perspective has been explored and elaborated in a large number of organizational studies and approaches.

As it has been discussed above, the *work organization*, is determined by the control requirements of the work domain and by the role configuration architecture chosen by or imposed on a group of cooperators. The necessary coordination of the cooperating individuals following from this architecture will specify the *content* of communication. On the other hand, the architecture of the *social organization in the sense discussed above* will determine the *form* of the communication, i.e., on the conventions and constraints chosen for this communication. Consequently, different structures of the social organization are possible for coordination of activities, more or less independent of the task and role configuration principle adopted and the characteristics of the work domain:

Autocratic Coordination

One decision maker is responsible for the coordination of the activities of all other agents. This mode of meta control of coordination is, of course, mostly applicable when one person is controlling the mode of coordination in a smaller, private company. One manager acts as a roving coordinator making sure that priorities are right in the working network.

Hierarchical Coordination

Very often, coordination is distributed in an organization which is stratified such that one level of decision makers evaluates and plans the activities at the next lower level. This hierarchical structure has its roots in the American, military command, control and coordination paradigm. It is based on the fact that in a large organization, the information traffic and the time requirements to the pace of response can be arranged in several distinct levels. This is the case for a system of very specialized actors, such as those involved in a military mission. Very large information volumes have to be communicated at the lower levels with very short time horizons while data traffic decrease and time horizon becomes wider as one moves to the more strategical levels. Different coordination, or management styles, are possible within this structure depending on whether the communication downward through the system is based on communication of goals (the military model) or on communication of procedures (the bureaucratic model).

In modern organizations, the hierarchical structure is normally maintained for formal functions such as allocating legal responsibility and economic competence, whereas more flexible (and often informal) management structures are accepted for the more dynamic work coordination. This is the case even in military organizations in which the formal rank structure is abandoned when high-tempo coordination of activities across levels and units is required (see for instance Rochlin et al., 1987).

Heterarchic Coordination

In the general, dynamic work situation the formal hierarchical structure disappears, even in military organizations. The work of Rochlin et al. (1987) shows a pronounced ability of the organization on an aircraft carrier to shift between a formal rank organization, a flexible, self-organizing 'high-tempo' work coordination across ranks and organizational units, and a flexible emergency organization depending on the immediate requirements of the actual situation. Similar organizational forms are necessary in modern commercial enterprises adopting a flexible customer driven policy in a dynamic and competitive market, see the discussion in the introduction.

For the coordination of activities in such a flexible organization, several meta-strategies can be adopted to shape the coordinating activities:

Negotiating Coordination

The individual decision makers negotiate with their immediate cooperators and the necessary communication is locally planned. This mode is typically found when coordination planning has to be arranged ad-hoc on occasion, i.e., when high-tempo performance is required in very flexible and dynamic situations for which particular patterns of 'contracts' are evolving (Winograd and Flores, 1986).

A similar mode of coordination has been called *debative cooperation*. In complex decision tasks one individual decision maker will not have the necessary conceptual background, nor the required information on the state of affairs. In addition, conflicting goals and criteria must be resolved. The cooperation, therefore, involves debate and negotiation among agents with different heuristics and perspectives.

Anarchistic planning

Each agent plans his own activity without interaction with other decision makers on the meta level. Communication is entirely through the work content.

Democratic planning

Coordination involves interaction and negotiation among representatives of all decision makers of the organization (worker participation committees). This mode is frequently found in companies when there is a reasonable time horizon for planning and special meetings and frames for the planning can be arranged.

It will be evident that these different architectures will imply, or evolve from, different forms of communication among agents, i.e., whether information is passed as neutral information, advice, instructions, or orders. The effective way of influencing the social organization independent of the work organization will be through constraints and conventions for communication.

Discussion

Systems Point of View

The social interaction among the agents depends on the form of the communication exchanged for coordination, which in turn depend on the coordination strategy adopted. The work organization is determined by the work domain and the role configuration, while the social organization is evolving from the coordinating control requirements and the strategy adopted for this purpose.

Independent on the task and role configuration principle adopted and the characteristics of the work domain, different structures of the social organization are possible for coordination of activities. It will be evident that these different architectures will imply, or evolve from, different form of the communication among agents, i.e., whether information is passed as neutral information, advice, instructions, or orders. The effective way of influencing the social organization independent of the work organization will be through constraints and conventions for communication.

In control theory, distinction is frequently made between several different strategies for coordination of hierarchical systems. In complex, large scale technical systems, functions are normally decomposed in order to identify a hierarchy of units which can be functionally 'decoupled' in order to structure the information traffic in an optimal way (See e.g., Mesarovich, 1970, Schoeffler, 1969). Coordination of the functional units can then be obtained through 1.) manipulation of goals of lower levels or parameters of these goals; 2.) through manipulation of constraints of lower levels, i.e., restriction of the domain of their control actions; 3.) through manipulation of interaction variables between units from estimation or prediction and, finally, 4.) through manipulations of the information available to the units at lower levels, etc.

The formal models and theories developed for design of hierarchical control of complex technical systems can be useful for testing consistency and structure of cognitive models of social systems.

Work Psychology Point of View

All collective activities require coordination of the individual activities depending on characteristics of tasks and groups. Different mechanisms and means can be used for this coordination (see Leplat, 1988):

1. **Coordination of Goals.** Coherence in representation of goals is needed, but even then, different criteria can be adopted (speed—accuracy, production, security, comfort) for performance evaluation.

2. **Common Referential.** In collective activity, the functional representation, shared by the individuals constitutes the common referential. Description of common referential is often linked to acquisition of knowledge. Common language, Falzon's operative language. Common referential is important in a group with no a particular coordinator.

3. **Situations of Guidance,** so called by Savoyant (1981) when one individual takes decision in collective work. Necessary when:

- Information centralized, executor cannot identify relevant properties of object or
- Hierarchical organization of labor imposes control.
- Guidance can be given in terms of: goals, sub goals, and procedures.

These distinctions appear to be based on a classical task analysis and procedures oriented approach, a more basic analysis including consideration of the intrinsic coupling and control requirements of the work domain should be tried.

4. **role of work load in coordination.** The individual regulated work not only considering effectiveness but also efficiency, i.e., achieve the goal with the least possible cost. (This distinction between effectiveness and efficiency is a special case of the distinction between product and process criteria. Process criteria will not necessarily be related to cost, but also to joy, creativity, excitement, etc.).

5. **Function of communication in Coordination.**

- **Quantitative Analysis of Communication.** Recording of number of remarks depending on task demands, etc.
- **Functional and Social Communication.** Second type plays a role in social regulation, increases with familiarity of group with task.
- **Classifying Functional Communication.**

Savoyant and Leplat distinguishes between planning, execution, and control (i.e., monitoring). Communication needs:

- general orientation prior to performance,
- limited orientation during action,
- control information during execution,
- control communication ensuring that certain conditions are achieved.

6. **Automatization of Coordination.** Automatization implies the decrease of the need for communication. To help the reduction of communication, several means are available.

- temporal references based on regularities in the task (i.e., internal, dynamic model),
- external references, environmental signals (signs in my terminology,
- categorization of situations, used to simplify messages (i.e., rule-based action focus).

Information characteristics depend on the degree of uncertainty (Stoelwinder and Charns, 1981), and requirements for information exchange can be reduced, in case of low uncertainty by:

- standardization of work processes, rules, procedures, schedules,
- standardization of skills,
- standardization of output, results are specified,

In case of high uncertainty by:

- supervision, one coordinates
- mutual adjustment, agents exchange information,
- group meetings, work groups.

Management Theory Point of View

In his synthesis of modern organizational theory, Mintzberg (1979) identifies a number of coordinating principles that “seem to explain the fundamental ways in which organizations coordinate their work”:

- mutual adjustment, i.e., coordination of work by the simple process of informal communication;
- direct supervision, i.e., coordination of work by having one individual take responsibility for the work of others;
- standardization, i.e., coordination of work by anticipation. In the words of March and Simon (1958), the coordination of work elements is incorporated in advance in the program or plan for the work when it is established, “and the need for continuing communication is correspondingly reduced.”

Again, Mintzberg identifies three different ways to achieve standardization in organizations:

- standardization of work processes;
- standardization of work outputs;
- standardization of worker skills.

These coordinating mechanisms constitute the basis, Mintzberg argues, of a set of ‘structural configurations’ of organizations, see figure 29.

<i>Prime Coordinating Principle</i>	<i>Structural Configuration</i>	<i>Type of Decentralization</i>
Direct supervision	Simple Structure	Vertical and horizontal centralization
Standardization of work processes	Machine Bureaucracy	Vertical centralization and limited horizontal decentralization
Standardization of skills	Professional Bureaucracy	Vertical and horizontal decentralization
Standardization of outputs	Divisionalized Form	Limited vertical decentralization
Mutual Adjustment	Adhocracy	Selective decentralization

Figure 29. The relationships between different coordinating mechanisms, different structural configurations, and different types of decentralization, according to Mintzberg (1979).

Coordination in the *Simple Structure* is effected largely by direct supervision. Specifically, power over all important decisions tends to be centralized in the hands of the chief executive officer. While most organizations pass through the Simple Structure in their formative years, this type of organizational configuration is primarily found in organizations with non-sophisticated technical systems operating in simple and dynamic environments.

In the *Machine Bureaucracy*, on the other hand, coordination is affected largely by standardization of work processes. Accordingly, this type of configuration is characterized by formalization of behavior, vertical and horizontal job specialization, vertical centralization and limited horizontal decentralization. The Machine Bureaucracy is primarily found in environments that are simple and stable.

The *Professional Bureaucracy* relies for coordination on the standardization of skills and its associated design parameters, training and indoctrination. This type is characterized by horizontal job specialization and a high degree of vertical and horizontal decentralization. In control of his or her own work, the professional works relatively independently of his or her colleagues. This type is primarily found in complex and stable environments with non-sophisticated technical systems.

The *Divisionalized Form* relies on the third form of standardization, standardization of outputs and the concomitant design parameter, the performance control system. Like the Professional Bureaucracy, the Divisionalized Form is not so much an integrated organization as a set of quasi-autonomous entities coupled together by a central administrative structure. And in the case of the Divisionalized Form each entity has its own structure. Primarily found in organizations faced with diversified markets (particularly products or services), the Divisionalized Form is characterized by limited vertical decentralization.

Finally, in the *Adhocracy*, the prime coordinating mechanism is mutual adjustment. The Adhocracy is characterized by a high degree of horizontal job specialization, little formalization of behavior, and selective decentralization. Effective in fusing experts drawn from different disciplines into smoothly functioning ad hoc project teams, the Adhocracy is highly fit for the 'sophisticated innovation' required by organizations in complex and dynamic environments.

4. Values and Functional Requirements, Role Configuration and Management Styles

In the previous paragraphs a very clear and simplistic distinction has been drawn between the *work organization* and the *social organization* and their roles in the work coordination. Distinction has been made between the criteria that control the partitioning of activities, the allocation of roles to individuals and the resulting, necessary *content* of communication for coordination and the criteria that govern the coordination management implemented in the *form* of communication.

This is clearly a simplistic distinction, since many factors will cut across this distinction and make the picture much more complicated. This, however, does not affect the

general structure of the taxonomic representation aimed at in the present report. It will, however, be important to relate the discussion to the more established distinctions in the sociological and management science approaches. This is the topic of the following review:

Labor power is an attribute of human individuals and, hence, cannot be separated from the individual. An individual joining a cooperative ensemble is motivated by individual interests (to earn a wage, make a career etc.) and brings along a complex of aspirations and expectations. A cooperative work process, then, is performed by individuals with individual interests and motives. Because of that, organizations must be regarded as coalitions of diverging and even conflicting interests rather than perfectly collaborative systems. An organization is not an entity acting as if guided by a single will. It is not a perfectly collaborative system. Rather, an organization is a mixture of collaboration and conflict.

This point was brought home by the so-called Carnegie School in organizational theory (Simon, 1945; March and Simon, 1958; Cyert and March, 1963; Thompson, 1967). An organization is not characterized by unity of interests; it is not monolithic. On the contrary, it is a “coalition” of individuals motivated by individual interests and aspirations and pursuing individual goals (Cyert and March, 1963). In the words of Pfeffer and Salancik (1978), “The organization is a coalition of groups and interests, each attempting to obtain something from the collectivity by interacting with others, and each with its own preferences and objectives.” This perspective has been investigated from a rich variety of approaches e.g., the ‘negotiated order’ approach developed by Strauss and associates (Strauss et al., 1963), the ‘garbage can’ model of March and Olsen (1979), and the ‘conflict’ approach of Collins (1975).

This perspective has been developed further by the ‘transaction cost’ approach developed by Williamson (1975, 1981), Ouchi (1980), Ciborra (1985), and others conceives organizations as contractual arrangements between opportunistic partners. In the words of Ciborra (1985):

“Organizations are seen as networks of contractual arrangements to govern exchange transactions among members having only partially overlapping goals. Conflict of interests is explicitly admitted as a factor affecting information and exchange costs.”

Thus, according to Ciborra, this approach allows us to grasp “the daily use of information for misrepresentation purposes in partially conflictual organizational settings.” According to Ciborra, most information generated and processed in organizations is subject to misrepresentation because it has been generated, gathered and communicated in a context of goal incongruence and discord of interests and motives.

In accordance with the prevalence of goal incongruence in organizations and the partially conflictual nature of organizations, allocation of tasks is just as controversial. As pointed out by Strauss (1985), 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.”

Workers may agree or disagree with the allocation. But they may also conceal their disagreement. They may reject it but not reveal their rejection, or they may reject it and act on that basis but conceal their rejection. They may also agree or disagree to the criteria of the tasks for which they are made accountable, and they may again disagree overtly or covertly.

The interactions of interests, motives, expectations etc. produce a number of organizational forms that are superimposed on the social relations of the work organization, for example:

- The customary privileges and prejudices of task allocation: Does the specific allocation of tasks and the concomitant pattern of interaction reflect specific professional or individual privileges? One type of task may be felt, by an elevated category of workers, to be an insult while another category of workers may defend the same task as their prerogative.
- Institutional forms of manifestation and regulation of conflicts of interest, etc.: Labor organizations like trade unions and work place organizations like, for instance, shop steward committees may exert massive impact on the allocation of tasks to various categories of workers. A class of tasks like, say, CNC programming, may be monopolized by the members of one labor organization, thereby generating a specific pattern of social interaction in the labor process. That is, the competitive and collaborative relations of the various labor organizations may affect the structure of social interactions.
- The system of incentives (promotion, reward and remuneration): To which extent and how are individual agents encouraged to behave in accordance with the demands of the work environment. The system of remuneration may complement and enhance the performance measurement system, or it may conversely counteract it (for instance by not assigning the cost of deficient products to the agencies in power to take corrective measures).
- The forms of social control in the work place: For example, to what extent is horizontal information flow among the collaborators regulated, inhibited, or impeded by preordained hierarchical lines of communication, that is, to what extent is the cooperative process mediated by a superimposed structure?
- The forms of allocation of power and authority: For instance, is a person furnished with authority by his peers in recognition of his contribution to the accomplishment of the objectives of the collective, or is authority furnished by investiture by some extrinsic power?

It should be noted that formal organization, strictly speaking, is a perspective that applies to the work organization as well as the social organization. If the term 'formal' is taken to mean determined by explicit rules, the distinction formal-informal is orthogonal to the distinction social-functional. Normally, however, the term 'formal organization' denotes formalization of relations of the social organization. The objective of formalization of collaborative relations (such as allocation of resources, task allocation, procedures, etc.) is to ensure accountability. In this perspective, formalization is a mechanism for *social control* of cooperative work relations. If need be, who is to blame?

In this sense, formal organization is a superimposed structure safeguarding the interests of the proprietary and regulatory bodies. Accordingly, formal organization reflects the relations of property and codifies the cooperative relations in a legally valid form (e.g., by contract, statute, authorization), thus serving the function of allocation of resources, responsibilities and, when appropriate, disciplinary measures. In some very special cases where the work environment is characterized by a high degree of stability and tasks are highly routinized, the real organization may appear as being congruent with the formal organization. In most domains, however, the actual pattern of cooperation changes dynamically, according to the requirements of the situation. In these cases the formal organization is only faintly congruent with the real organization.

7. Level of Cognitive Control

At a very early stage we have developed a taxonomic structure covering the mental representations, the interpretation of information, and the cognitive control structure as depending on the level of expertise of an agent in a particular situation in terms of the skill-, rule-, knowledge-framework. This framework is compatible with the main-line of conceptualization within cognitive science and psychology (declarative vs. procedural knowledge, frames and semantic nets, etc.), which the MOHAWC concepts should also be in order to communicate the results of field studies to the cognitive science community.

Description

This domain of description defines the characteristics of the actual agents, their level of expertise, their education and competence, and the dimensions of the possible subjective preferences and performance criteria which they may bring to work. The aim is an identification of the cognitive control structure an agent can apply to the task, depending on background and expertise. The resources available to an agent depend very much on the cognitive control structure in action and an analysis in this domain can serve as a basis for allocation of decision roles to individual agents. Humans have different modes of control of their goal oriented interaction with the environment. Sensory-motor routines take care of the direct control of integrated patterns of movements during familiar circumstances.

Interaction at the sensory-motor skill level is based on real-time, multi-variable, and synchronous co-ordination of physical movements with a dynamic environment. Quantitative, time-space signals are continuously controlling movements, and patterns are interpreted as signs serving to adjust the world model and maintain synchronism with the environment. The dynamic control of the patterns depends on high capacity signal processing in a feed-forward mode governed by the internal world model. During run-off of such routines, the conscious attention is free to cope with other matters on a time sharing basis. At the rule-based level, the conscious attention may run ahead of the skilled performance, preparing rules for coming requirements. It may be necessary to memorize rules, to rehearse their application, and to update more generic rules with the details of the present environment. Stored rules will frequently be formulated at a general level and, therefore, will need to be re-formulated and supplemented with details from the present physical context. In other cases, rules are not ready in explicit formulation, and previously successful coping with a similar situation will have to be memorized to establish transfer. In general, control at the rule based level require conscious preparation of the sequence ahead of the timing of the skilled run-off, if not, a break in the smooth performance will take place. The conscious mind only very infrequently is operating in synchronism with the interaction with environment. The attention will wander ahead to identify the need for rules, and backwards, to recollect the rules of past encounters. If none is available, switch over to deduction of rules by means of 'a mental model' is required which, in general will require even more foresight if a break in performance is not to occur. In this case, thought experiments and causal reasoning at the knowledge-based level

will be necessary. One important feature of this complex interaction is the incessant change of the control and its allocation to the different levels which take place as high skill evolves. Control moves from level to level and the complexity of behavioural patterns, rules and models within levels will grow with training. For a more detailed discussion see Rasmussen, 1986.

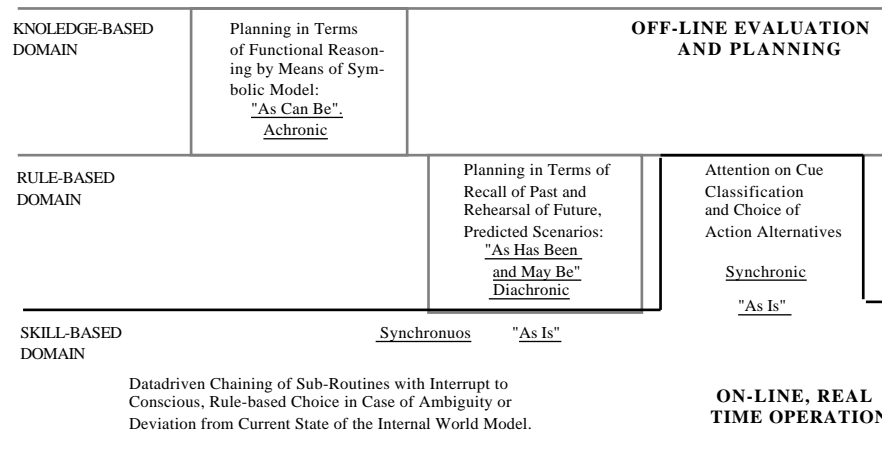


Figure 30 illustrates the complex interaction between the different levels of cognitive control. Tasks are frequently analyzed in terms of sequences of separate acts. In general, however, control of several acts takes place concurrently. At the level of skilled sensorimotor control, activity is like a continuous, dynamic interaction with the environment. Attention, on the other hand, is scanning across time and activities in order to analyze past performance, monitor current activity, and plan for foreseen future requirements. In this way, the internal, dynamic world model is being prepared for oncoming demands and the related cues and rules are rehearsed and modified to match predicted requirements, and symbolic reasoning is used to understand responses from the environment and to prepare rules for foreseen but unfamiliar situations. Attention may not always be focused on current activities, and different levels may simultaneously be involved in the control of different tasks, related to different time slots, in a time sharing or in a parallel processing mode.

During learning and adaptation to a work environment, it is not the behavioural patterns of the higher levels that are becoming automated skills. Automated time-space behavioural patterns are developing while they are controlled and supervised by the higher level activities - which will eventually deteriorate - and their basis as knowledge and rules may deteriorate.

Modern technological systems have several characteristics which influence the natural allocation of control of action to the different cognitive levels. In natural environments, the interaction will typically be controlled at the two lower levels. Work will be related to manipulation of objects in a more or less familiar setting. If exceptional situations occur, the effect of decisions will typically be reversible and interaction can be like an explorative navigation through new territory. The interaction with modern technical systems have features which are very different. Frequently, such as for instance it is the case for process plants, the process to be controlled will be invisible and control will be indirect in the sense that there is no simple mapping between features of the system surface which are the objects of skilled sensory-motor manipulation and the actual control object, the chemical or thermodynamical process. In addition, effects of inappropriate acts may be irreversible and lead to very great losses. Consequently, there is typically not the harmonious relation between manual skill and higher level activities which are found in more tradi-

tional work settings, and the need for control of actions from the knowledge or model based level becomes very pronounced in particular for control of the unusual conditions which is typical for automated systems.

Application

Planning of action at the knowledge based level in its pure and systematic form is characteristic of work like research and engineering design. Such activity is based on search and inference in a problem space of conceptual, frequently causal or means-end relations representing the functional properties of the work domain. These activities are typically supported by formal calculation or simulation tools. In modern complex systems, operators have to cope with disturbances and faults by reconfiguration of the components of the system, frequently why it is still operating, in order to protect plant and/or production. If the particular situation has not been foreseen by the designer and the operating staff properly instructed, the task is, in fact, a supplement or continuation of a design task which could not be completed by the designer himself. Consequently, it will require the same kind of knowledge based behaviour as the design itself and unfortunately under much more difficult circumstances.

The basic problem in this situation is that, for modern, reliable systems, situations calling for actual knowledge-based reasoning will be infrequent and, therefore, the knowledge required to cope with them will degenerate during the adaptation to the work requirements, as it was discussed above. Another argument against the requirement that plant operators should be able to reason at abstract functional levels has been that this way of reasoning is unnatural for operators who normally think in terms of physical components and their behaviour. During major disturbances, operators are supposed to take over control. However, the task will not be to take over the usual automatic control. The plant will typically require the operating staff re-designing plant configuration and operating procedures to meet the abnormal condition. For this task they have to understand the basic process. A keeping-the-man-in-the-loop philosophy will not solve the problem of the rare events, since normal operation will not support the required knowledge. For large scale, high risk installations, therefore, other solutions are necessary. It will be required to supply at the surface of the system an adequate representation of the internal process of the system, to arrange an education of operators reflecting the new requirements, and to change the organization of work in order to give them tasks between disturbances that will maintain their basic knowledge and supply the proper intuition at the conceptual level.

It follows that analysis of the cognitive level of control and the respective different structures of mental models required, depending on the nature and frequency of a decision task, is very important for design of interfaces which will support the novice without frustrating the expert.

Classes and Terminology of Cognitive Resources and Competence

a. Type of Knowledge in Mental Representations

A taxonomy of mental representations can be proposed. It is proposed to restrict the term mental model to the representation of the 'relational structure' of the environment, to follow Craik's definition. This means, the mental model is a representation of the fundamental constraints determining the possible behaviour of the environment, i.e., it is useful to anticipate its response to acts or events when instantiated by state information. The study of errors have made it clear that a taxonomy of representations should not only consider the higher level cognitive functions related to inference and reasoning, the role of the body in the control of sensori-motor performance is an integrated part of the system. In the following section, the representations related to actual working performance according to the skill-,rule-,and knowledge distinction are discussed in more detail.

Declarative Knowledge: Representations at the Knowledge-based Level

In the present context, the representations at the knowledge-based level constitutes the proper 'mental models' being representations of the relational structure of the causal environment and work content. Two kinds of relationships, i.e., part-whole and means-end relations appear to be particularly important for the specification of the content and direction of problem solving processes and will be considered in some detail. These two dimensions constitute the problem space.

A number of conceptual relations, in addition to *part-whole and means-end relations* are useful for operation on a problem representation in the knowledge-based domain. When means for action has been chosen from perceived means-end relations in a particular work context, *causal relations* are used to judge the effect of actions. *Value aspects* are important for choice and for assignment of priority in decision situations when the constraints given by goal specifications and functional requirements leave freedom for optimizing consideration, as for instance related to cost, reliability, effort required, emotional aspects, etc. Choice among possible strategies in a work situation will depend on *performance criteria*, i.e., value aspect assigned to the work process, as well as its product. *Generic relations* define a concept as a member of a set or category in a classical Aristotelian classification, and can be used to label part of the environment and assign it to a category for which functional properties are readily available. The generic relations are, in particular, useful for drawing formal logical inference (syllogistic reasoning).

Procedural Knowledge and Scripts: Representations at the Rule-based Level.

At the rule-based level, system properties are only implicitly represented in the empirical mapping of cue-patterns representing states of the environment and actions or activities relevant in the specific context supplied by the underlying dynamic world model.

According to the definition adopted here, this representation does not qualify as a mental model since it does not support anticipation of responses to acts or events not previously met, and it will not support explanation or understanding except in the form of reference to prior experience. In order to prepare for rule-based control of activities, however, conceptual relations may be important. Descriptive relations are useful in assigning attributes to categories and, therefore, to label scenarios and contexts for identification of items to retrieve from memory. In this aspect, the terminology is connected to the terminology applied for description of the activity in domain terms.

Frames and Episodic Representations: Representations at the Skill-based Level.

Performance at the skill-based level depends on a dynamic world model which has a perceptual basis, like Johnson-Laird's mental model. The model is activated by patterns of sensory data acting as signs, and synchronized by spatio-temporal signals. This conception is similar to Minsky's (1975) "frames". The main - and fundamental - difference is that Minsky's frames depend on a sequential scene analysis; they are structured as networks of nodes and relations, and they are basically static. The "dynamic world model" in the present context is very similar to the mechanisms needed for the "atunement of the whole retino-neuro-muscular system to invariant information" (Gibson, 1966, p. 262), which leads to the situation where "the centres of the nervous system, including the brain, resonate to information". This selective resonance relies on the existence of some kind of dynamic model of the environment.

b. Extent of Knowledge

To be added

c. Basic Cognitive Process Elements of Mental Strategies

Association

Induction

Deduction

Hypothetico-Deduction

Search

Comparison and Choice

Evaluation

d. Ability to Use Knowledge

To be added

e. Performance Criteria

What are the subjective criteria used to resolve a choice among possible strategies:

- Cognitive strain,
- Cost of observations
- Fear of failure,
- Joy of learning,
- Elegance in inference process

f. Meta-Cognitive Knowledge

To be added

Semantic Interpretations

Distinction between *signals*, *signs*, and *symbols*. The reference to the mental model categories, and the tactical rule sets.

Action Trajectory: Folding Preferred Strategy onto Context

The aim of the taxonomy is to be able to compare behavior shaping characteristics of different work domains and, in particular, to be able to predict behavior in response to changes such as introduction new information systems from analysis in an existing work place. It will not be possible to predict the particular trajectory of work of an individual. Based on a description following the taxonomy, however, it will be possible to define the boundaries given by the work requirements, the resources for work, and the individual's physical and mental resources within which the individual will generate the particular trajectories depending on the situation and person depending performance criteria and preferences (cf. Bateson; the category can be known, the particular escapes prediction). In this sense, the taxonomy implies a theory of adaptive behaviour. In response to changes of work conditions, adaptation is active and behaviour of the actors cannot be described in terms of work procedures or decision scenarios which will only be records of observed cases, not predictive models of performance.

Activity under varying conditions will depend on continuous adaptation and improvisation, on the ability to re-configure patterns of behaviour, to modify effective routines, to combine elementary routines into new patterns and to generate new work procedures on demand. Therefore, only analysis and representation following the taxonomy, i.e., based on an explicit representation of the behaviour shaping constraints as posed by the goals and constraints which define acceptable work performance and of the constraints as posed by the goals and constraints which define acceptable work performance and of constraints as posed by the tools and means available for work, can be used for prediction of the of the category of behaviour to expect in response to changes. These constraints will define the boundaries of the space in which the actors can navigate freely according the their individual resources and subjective performance criteria and still meet the work requirements. In this way, the taxonomy serves to delimit the field within which behaviour will unfold. Hypothesis about the likely performance of an agent can be stated under proper assumption about the resources and subjective preferences of the individual actor. Prediction of the actual trajectory of performance is less important for design of information support systems. Instead, of importance is an evaluation of the capability of the agent to perform under assumption of certain individual resources and subjective preferences, i.e., whether an agent can meet requirements and will accept the conditions. Basically, this is a feed-back design approach: You specify the criteria functions and secure the capability, then acceptable performance will emerge given the actors are concerned. The capability includes competence in using the means available and ability to explore the options present. In order to predict a likely work scenario, a hypothesis is formed about the actor's selection among the strategies which can be used in the work situation and task considered. This strategy, which is an abstract representation of a type of behaviour should then be folded back onto the work domain. This means that the abstract construct in cognitive terms is instantiated by dressing it up with the details of the

material work content and situational features. The prediction will be prototypical in the sense that it will miss all the details of the situation which are not to be known, such as disturbances and distractions from the general social interaction and the frequent shifts in strategy in response to resource demand conflict and to situation depending shifts and subjective preferences. This however, does not affect the reliability of the prediction for design of information systems nor prediction of the effect of introduction of new information systems on work performance. It does, however, influence the possibility of evaluation the results of attempts to predict performance. Being prototypical, prediction involves categories of behaviour, while actual performance trajectories (as well as simulation of predicted scenarios) represents particular instances and comparison is no simple matter (see Rasmussen, Brehmer, and Leplat, 1990). A typical feature of prototypical classification is the difficulty in definition of members, the most effective way is generally to point to a typical example. In the same way, the best way to evaluate predicted work scenarios may be to show it to a group of “substance matter experts” (i.e., workers in the field) and ask whether they find the scenario to be “reasonable” and natural.

C. CLASSIFICATION SYSTEM

A Facetted Classification System

In the preface of this report one of the stated purposes of the MOHAWC taxonomy is to be a methodological tool for planning field studies and collecting data in work domains. In order to support the use of the taxonomy for this activity, a classification scheme is proposed, which provides a brief review of the facets and classes which can serve to point the attention of the analyst in a field study to features of the work environment, the task, and the characteristics of actors which are potential behavior-shaping constraints and, therefore should be examined in detail and which should be carefully considered for information system design. At the present state of the art, the classification scheme is not intended to be a simple categorisation scheme for work environments, tasks or actors. For this purpose we need to define 'prototypical members' of the various classes and higher level prototypical relationships among categories, which will effectively facilitate the proper specification of advanced information systems from more pointed and less exhaustive field analyses than are necessary at the present stage.

The still increasing need for classification of complex subject matters in information retrieval led to a need for leaving the traditional classification theory and practice based on the logical principles of Aristotle and inherited primarily from the theoretical attribute classification in biology. The disadvantages of these systems is primarily their lack of attention to the special point of views of the users' and their need for unconventional combinations of several subjects for a coherent and adequate description of a concept, independent of formal classification rules. Especially the need for very specialized schemes in limited knowledge domains with intensive research results has motivated the extensive studies and implementation in information science of *facetted* classification schemes. Ranganathan was the first to propose an alternative to the rigid classification principles of logical hierarchies as is found in the numerical, decimal classification systems. He developed a flexible, facetted or analytic-synthetic classification method, in which facets are not locked by a rigid enumeration in a hierarchical scheme, but can be combined quite freely, i.e. any relationship between concepts can be expressed. Originally Ranganathan argued that all knowledge, any subject matter, could be exhaustively described by 5 fundamental categories: Personality, Material, Energy, Space and Time. If possible, such kind of fundamental categories in a knowledge domain can form the conceptual framework needed to explore and develop relevant division criteria for the different facets of a scheme. In the MOHAWC taxonomy in part A so far two fundamental categories have been proposed:

1. The socio technical *work system* and its interaction with the environment.
2. The *agent* of the work system and his/her interpretation of the state of the system and the action alternatives.

The seven different facets (figure 8) within which classes have been established have been derived from these two fundamental categories.

The pragmatic emphasis on the use of a scheme in a particular *user group* implies that the techniques and rules for the implementation of a facetted scheme has to be determined

with respect to the domain in question, the purpose of the scheme and the preferences of its users. Another objective of the faceted classification is to provide a birds eye view of all the relationships of subjects. The one sided emphasis of hierarchical relations in an enumerative classification is set aside to the advantage of new, possible combinations. New inter-relatedness can be shown, for instance by the *order* of the facets, which usually reflect the order in which the concepts of a given subject domain is related and should be combined and represented.

The flexibility of a faceted classification is also due to the use of *cross classifications* within facets which thereby allow the repetition of *common* facets and classes within all the relevant facets. Furthermore, it is possible to combine obligatory related concepts by means of *differential facets*. In such cases one or more classes in one facet is always followed by classes from another facet, a feature which can be particularly useful in cross disciplinary studies.

Psychological Task Classification

The terminology in this draft paper is used in exactly the same sense as defined by Fleischmann, namely :

The term *taxonomy* means the theoretical study and formulation of the basis, principles and procedures of a systematic classification. *Classification* is the implementation of the theoretical basis in the process of ordering and establishment of classes and identification of entities belonging to classes. The final product of such efforts is then called the *classification system*.

According to Fleischmann many developers of schemes within task psychology follow - some even first and foremost - the demands of logical, objective and exclusive classes, but some are either indifferent to such rigid principles or they have great troubles with the accomplishment of a match between the rigid categories of a traditional classification and the description of their problem and the entities of their research. Fleischmann claims that the internal validity of a scheme depends on its consistency with such well known classification rules. However, as mentioned in a previous chapter of this paper, the complexity of a modern work system with information technology cannot be sufficiently analyzed in terms of a one dimensional, hierarchical model. The shortcomings of common, standard classification methods for the analysis of complex domains of knowledge as originally recognized by Ranganathan seems to have caused the same problems for some work psychologists. Previous attempts to go beyond the task descriptions and include dimensions somewhat similar to the MOHAWC classification have been made by Miller, who included information processing strategies, and by Moors, who included situational/organizational context.

So far, there seems to be two main differences between the taxonomies of human performance reviewed by Fleischman, and the present MOHAWC taxonomy:

1. The conceptual, theoretical basis of the classification system refers to a complex work system - not primarily agent, training and task - which for the purpose of meaningful description is divided into seven dimensions/facets, each with its own, particular terminology.

2. Classes are not mutually exclusive and they are not exclusively related to one fixed location within one dimension: Some are common to a number of different dimensions/facets and thus occur repeatedly in several places. Some classes can occur as a division of another class, within the same dimension or within another dimension. The classification system represents related, overlapping and tightly coupled points of view.

Naturally, in such a scheme the definition of relationships of facets and classes will become a crucial issue.

MOHAWC Classification System

In part A and B in the former paragraphs a common MOHAWC framework for work analysis and system design is discussed. In the following, *the taxonomy is illustrated* by a classification system, i.e. a *brief review* of the dimensions with their associated classes, as they are introduced in part B. The classification system reflects the former experiences of the authors with investigations and methods for field studies in different work domains. Thus it is neither intended to be a tool for an exhaustive description of any work domain nor to possess the specificity needed for any kind of analysis. Its inhomogeneity with respect to number and variety of classes and subclasses within the different dimensions reflects the focus of our professional experience and the limits of our insight in the terminology of other, relevant scientific fields. Therefore extension of the discussion of the MOHAWC concept (and, if desirable, a subsequent further elaboration of the scheme) will be necessary to achieve a uniform, adequate coverage of classes relevant for field studies.

Our object for description, i.e. a work system and its agents, is divided by seven division criteria, which are defined by genus and differentium with the object of the taxonomy, into facets or dimensions. Within each dimension the classes are then organized hierarchically. Rows of classes within a hierarchy are then ordered alphabetically (this will be done in relation to the list of terminology mentioned later on). The order of each dimension reflects the order in which concepts should be combined to form a meaningful synthesis of the analysis of a work system. The basic principle of order of the dimensions follows a logical way of representing the behaviour shaping constraints of a complex work context.

Apart from the main and general purposes of the taxonomy (described in D, Application Examples), which is, in summary, to improve prediction of new relationships, generate hypothesis, facilitate comparisons and interpretations / integrations / generalization of results of field studies and laboratory experiments, the current tentative classification system serves the following purposes:

1. It is a reductive representation which summarizes the discussion in part B about the units to be included and how to arrive at/derive classes and select terminology within each dimension.
2. It is a forerunner of the list of terminology with definition of terms, which the MOHAWC group has decided to develop in order to facilitate communication among researchers and in order to illustrate how results can be reported.
3. It is the forerunner of a structure which can be embedded in a database tool which can be designed to support collection and storage of data gathered in a work domain. Such a tool can - if the data are formatted properly - provide a direct mapping between the later information retrieval need of the investigators and designers of information systems and the analysis and description of a work system with its different configurations.

The analytical techniques used to establish the MOHAWC classification system are influenced by the the faceted classification approach, in particular the freedom it provides to determine procedures and principles for design of classes and facets solely in relation to the efficiency of the system for a particular application. The classes established are a combination of inferred classes and classes based on observations and empirical studies of the following work systems: Process control, hospitals, production systems, libraries and banks.

Thus the evaluation of this tentative draft should be based on the sense it makes to the MOHAWC partners and their perception of a potential match between dimensions/classes and work systems with which the partners are familiar.

Dimension 1: Means-Ends Structure of System

A: Elements of work domain

1. Elements in terms of the objectives of the system
 1. Goals and values
 1. Objectives, 'image'
 2. Products to offer
 1. Use of products
 2. Characteristics of products
 3. Volumes of products
 3. Services to offer
 1. Use of services
 2. Characteristics of services
 3. Volumes of services
 2. Constraints
 1. Legislation
 2. Financial relations
 3. Safety and ecological impact
 4. Workers' protection
 5. Union agreement
 3. Relations
 1. Stability
 2. Complexity
 3. Specificity
 4. Interdependency
 5. Variability
 6. Competition
 7. Locus of control
2. Elements in terms of Abstract functions
 1. Priority measures
 2. Material, mass
 1. Energy
 2. Information
 3. Manpower, people
 4. Monetary values
 3. Priority metric
 1. Amount
 2. Flow

3. Accumulation
4. Probability
3. General functions for which standard processes or established practice is present
 1. Staff functions
 1. Administration
 2. Accounting
 3. Marketing
 4. Product design
 5. Production planning
 6. Maintenance
 7. Production
 2. Technical functions
 1. Object shaping
 2. Object assembling
 3. Energy conversion
 4. Material conversion
 5. Process Control
4. Elements of Physical activities/processes with standardized equipment.
 1. Biological, physiological processes
 1. Functions, Ends served
 2. Characteristics,
 3. Criteria for choice
 4. Resources available
 2. Physical activities in work processes
 1. Functions, Ends served
 2. Characteristics,
 3. Criteria for choice
 4. Material resources available
 3. Technical processes within tools and equipment
 1. Functions, Ends served
 2. Characteristics,
 1. Mechanical
 2. Electrical
 3. Chemical
 3. Criteria for choice
 4. Material resources available
5. Material object inventory
 1. Premises, Buildings

1. Functions, Use served
 2. Characteristics:
 1. Kind, name
 2. Location
 3. Age
 4. Shape
 5. Size
 6. Weight
 7. Color
 8. Material
 3. Criteria for choice
2. Equipment
 1. Functions, Use served
 2. Characteristics:
 1. Kind,
 2. Location
 3. Age
 4. Shape
 5. Size
 6. Weight
 7. Color
 8. Material
 3. Criteria for choice
 3. Agents
 1. Functions served
 2. Characteristics:
 1. Profession,
 2. Education,
 3. Expertise,
 4. Age
 5. Address
 3. Criteria for Employment,

B. Structure of work domain

1. Complexity
 1. The size of the problem space
 2. Variety of functional elements
 3. Number of goals and objectives
 4. Compatibility of goals and objectives

5. Number of functional elements
 6. Number of connections among elements
 7. Uniformity or heterogeneity of work space
2. Integration
 1. Functional Structure
 1. Interaction among discrete objects
 2. Linear Flow
 1. River-structure
 2. Inverse river structure
 3. Parallel flow
 3. Continuous, distributed time-space flow
 2. Nature of connection
 1. material transport
 2. physical process
 3. information, communication of
 1. goal
 2. procedure
 3. advice
 3. Tightness of connection
 1. Hard coupling, immediate, functional connection;
 2. Moderate coupling, Decoupling through queues, piles, etc.
 3. Loose coupling, considerable decoupling through stores.
 4. Level of tight coupling:
 1. Coupling of material configuration, through
 1. Anatomical connection
 2. Topographic proximity
 2. Coupling of physical processes, through
 1. Physical interaction
 2. Exchange of information
 3. Coupling of general functions through
 1. Transportation of products and material,
 2. Exchange of information
 5. Predictability of coupling
 1. Stable and predictable
 2. Generally stable with disturbances
 3. Stochastic
 6. Temporal requirements
 1. Fast
 2. Moderate

- 3. Slow
- 4. Very slow
- 3. Source of Regularity
 - 1. Causal: laws of nature
 - 2. Intentional: Motives and objectives of other actors
 - 3. Formal: stable rules
- 4. Transparency of functionality
 - 1. Immediate visible, direct manipulation
 - 2. Mediated by interface

Dimension 2: Activity Within System

A. Delimitation of activity elements. Definition of the scope of analysis.

- 1. Delimitation in time
- 2. Delimitation by activities covered in Domain
- 3. Delimitation by characteristics of agents included
 - 1. Profession
 - 2. Competence
 - 3. Familiarity with task
 - 4. Work heuristics

B. Elements of prototypical work activity

- 1. Type of Activity (In domain independent terms)
- 2. Relational means-ends structure involved in activity
- 3. State of affairs in domain
- 4. Content of prototypical staff activity (generic classes of activities)
 - 1. Explore options in domain
 - 2. Maintain state of affairs in response to internal disturbances
 - 3. Change state of affairs in response to change of situation and goal
 - 4. Respond to external changes of requirements

Dimension 3: Decision Making

A. Activity in terms of prototypical decision making functions

- 1. Analysis of Situation
 - 1. Observation of Information
 - 2. Diagnosis of situation
 - 3. Identification of system state
- 2. Evaluation of Goals
 - 1. Prediction of Consequences in terms of goals and constraints

2. Identification of Options
 3. Identification of Resources
 4. Priority Judgement
 5. Selection of Relevant Goals
3. Planning
 1. Definition of task
 2. Planning of task procedure
 4. Execution
 1. Execution of procedure
 2. Monitoring

Dimension 4: Prototypical Decision Strategies

A. Mental Strategies

1. Analytical, model-based strategies
 1. Diagnosis
 1. Hypothesis and test
 2. Topographic search
 2. Information retrieval
 1. Analytical search
 2. Bibliographical search
2. Empirical categorization-based strategies
 1. Diagnosis
 1. Decision table look-up
 2. Information retrieval
 1. Search by analogy
3. Empirical recognition driven strategies
 1. Diagnosis.
 1. Recognition
 - 2 Information retrieval
 1. Empirical search
 2. Browsing

B. Elementary cognitive processes of strategies

1. Association
2. Induction
3. Deduction
4. Hypothetico-Deduction
5. Search
6. Comparison and Choice

7. Evaluate

C. Mental model necessary for applying strategies

1. Declarative, structural model
 1. Semantic network of users' universe
 2. Causal relationships
 3. Structure map
 4. Topography of tools
2. Library of symptom patterns
 1. Normal reference patterns
 2. Tacit template

D. Semantic Interpretation of observations in strategies

1. Symbols
2. Signs

E. Criteria for choice of strategies

1. Resource requirements
 1. Time
 2. Information
 3. Mental capability
 4. Physical capability
 5. Short term memory
 6. Long term memory
 7. Knowledge
 8. Experience
2. Task specific/Widely applicable
3. Sensitivity to disturbances

Dimension 5: Work Organization**A. Role Configuration Architecture (What is shared)**

1. Individual work
2. Cooperative work
 1. Collective work, load-sharing coordinated by:
 1. Physical coupling through work (e.g., assembly line)
 2. Communication from coordinator (e.g., conductor)
 3. Mutual communication (e.g., work song)
 2. Distributed cooperative work
 1. Domain oriented architecture
 2. Process oriented architecture
 3. Function oriented architecture

B. Criteria for Division of Work (How it is shared)

1. Formal role configuration
2. Functional de-coupling
3. Load-sharing
4. Agent competency
5. Allocation for problem-solving

C. Aggregation of Activities

1. Aggregation into task (For one person at particular time)
2. Aggregation into job (For one person across time)

Dimension 6: Management Structure

A. Autocratic coordination

B. Hierarchical coordination

C. Heterarchic coordination

1. Negotiating Coordination
2. Anarchistic planning
3. Democratic planning

Dimension 7: Cognitive Resources, Competence, and Preferences of Agents

A. Type of knowledge in mental representations

1. Declarative Knowledge/the knowledge-based level
 1. Aspects of mental models of functional content elements in the domain
 1. Part-whole relations
 2. Means-end relations
 3. Causal relations
 4. Value aspects
 5. Generic relations
 6. Myths and After rationalizations
 2. Procedural Knowledge/the rule-based level.
 1. Compiled declarative knowledge,
 2. Instructed declarative knowledge, Normative procedures,
 1. Situation based instruction
 2. Symptom based instruction
 3. Empirical procedural knowledge, heuristic
 1. Cue-Action correlations
 2. Know-how; production rules

3. Episodic scenarios

3. Frames and Episodic Representations/ the skill-based level.

1. Dynamic world model. Dynamic “frames”.
2. Scripts and Episodes
3. Patterns of movements

B. Extent of knowledge

1. Extent and scope of declarative domain knowledge
2. Size of repertoire of procedural rules
3. Size and smoothness of behavioural, movement patterns

C. Ability to use knowledge.

Categories to be formed

E. Subjective performance criteria for choice among possible strategies

1. Cognitive strain
2. Fear of failure
3. Joy of learning
4. Information economy
5. Elegance of inference process

F. Meta-cognitive knowledge about own situation, abilities and preferences

Categories to be formed.

G. Semantic interpretations

1. Reading symbols
2. Looking for signs
3. Seeing signals

D. USE OF THE TAXONOMY

Field Analysis of Work Performance

The framework is clearly developed for *analysis* of cooperative, cognitive work and it has been derived from efforts to understand and represent human performance in complex work context. The development, however, is ultimately aimed at design of advanced information systems. It has previously been argued (Rasmussen, 1988) that even if normative models of the design process can be useful for teaching, they are not suited for design of support systems. Design is a creative process which cannot be controlled by formal procedures. New ideas and concepts emerging during design have an intuitive basis, and conscious thought largely is used for evaluation and rationalization of the emerging design. For this evaluative analysis, the present framework is well suited serving systematically and explicitly to bring to the mind of a designer the various relationships influencing the match between work requirements and agent resources. Analytical evaluation of a conceptual design has many advantages to an empirical evaluation of complex systems (See e.g., Rouse, 1984). Apart from the obvious advantage, not to have to build complex prototypes for experimental work, analytical evaluation avoids the trap of finding what you are looking for. For empirical evaluation of complex systems there is no clear-cut stop-rule for termination of the manipulation of experimental conditions, if and when the immediate results turn out in conflict with the designer's expectations (Rasmussen, et al., in press), i.e., if the evaluation results are counter intuitive, it is a natural reaction to seek explanations in deficiencies of a complex experimental set-up.

Transfer of Research Findings to System Design.

Another application of the taxonomy can be the interpretation of research findings from psychological laboratory experiments and their transfer to a design application. An ultimate design objective will be to create a proper match between the cognitive task requirements in terms of useful mental strategies and the competence, cognitive resources and subjective preferences of the individual agent, within the envelope of acceptable activities as defined by work requirements and social constraints. If we, however, accept the point of view that performance of the individual agents is shaped in an evolutionary way by the creativity of the agent within the constraints of the work environment, it is necessary to demonstrate for the transfer of observations from laboratory experiments, that the constraints found in the work context and those embedded in the research context will lead to equal cognitive performance of the individual agent (See figure 1). When we want to analyze or predict selected cognitive phenomena, e.g., the mental strategies and models applied by a subject in an actual work situation or to test hypothesis from field studies by findings from selective experimental work in the laboratory, it implies that the transformation from the general requirements within in the source domain through task and situation dependent constraints to the representation of the phenomena under study should be explicitly known and should match the similar transformation from requirements within the research domain onto the representation. In consequence, if the behavior shaping constraints and the subjective criteria are not equal in the two cases, the *research domain must be distorted compared to the actual work domain in order to compensate for this difference*, i.e., the ‘cover story’ chosen for the experiment should be different from the actual task situation.

This concurrent analysis of the elimination of degrees of freedom in the actual work context and in the experimental setting is particularly important, considering the very different designs which are applied for different kinds of psychological experiments.

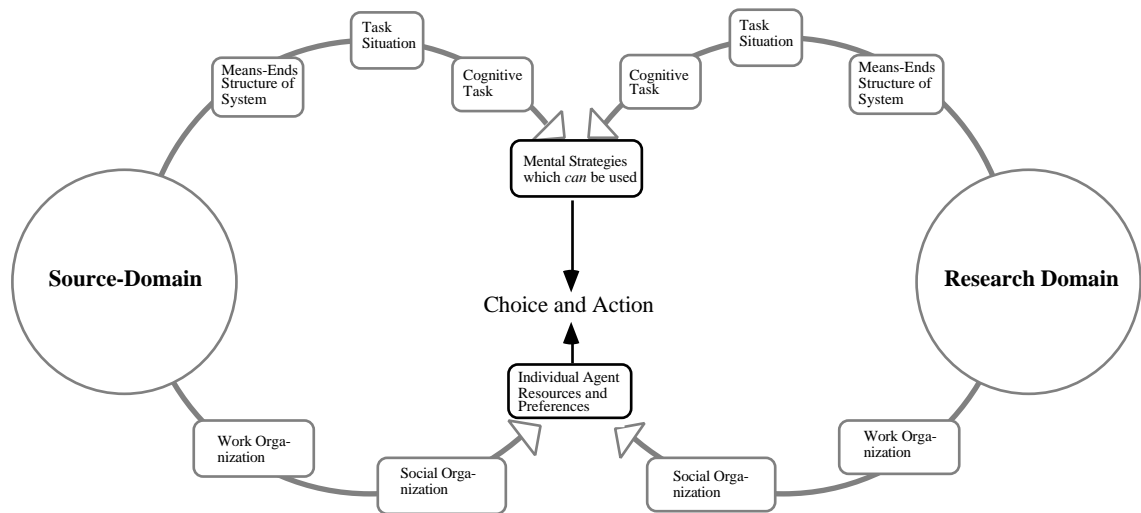


Figure 31 illustrates the assumption behind experimental and simulation work in the laboratory. We want to analyze or predict selected cognitive phenomena, e.g., the mental strategies and models applied by a subject in an actual work situation or to test hypothesis from field studies by findings from selective experimental work in the laboratory. In consequence, this implies the replacement of the work domain, the task situation and the actual decision task by equivalents in an artificial situation. In order to find results of relevance to the actual source domain, the transformation from performance in the source domain through task and situation influence to the representation of the phenomena under study should be explicitly known and should match the similar transformation from performance in the research domain onto the representation. In consequence, if the behavior shaping constraints and the subjective criteria are not equal in the two cases, the *research domain must be distorted compared to the actual work domain in order to compensate for this difference*, i.e., the ‘cover story’ chosen for the experiment should be different from the actual task situation.

Design of Psychological Laboratory Experiments

In laboratory experiments, as it is the case in actual work, serve as controllers of the state of affairs in a work environment. Consequently, the taxonomy should be well suited to characterize the structure and content of the experimental task and the functions and mechanisms brought to work by the subject. Psychological experiments have different purposes, and the experimental domain chosen will reflect these differences. The following sections present a preliminary discussion of the use of the taxonomy to characterize different types of psychological laboratory experiments.

Identification of Characteristics of Psychological Mechanisms

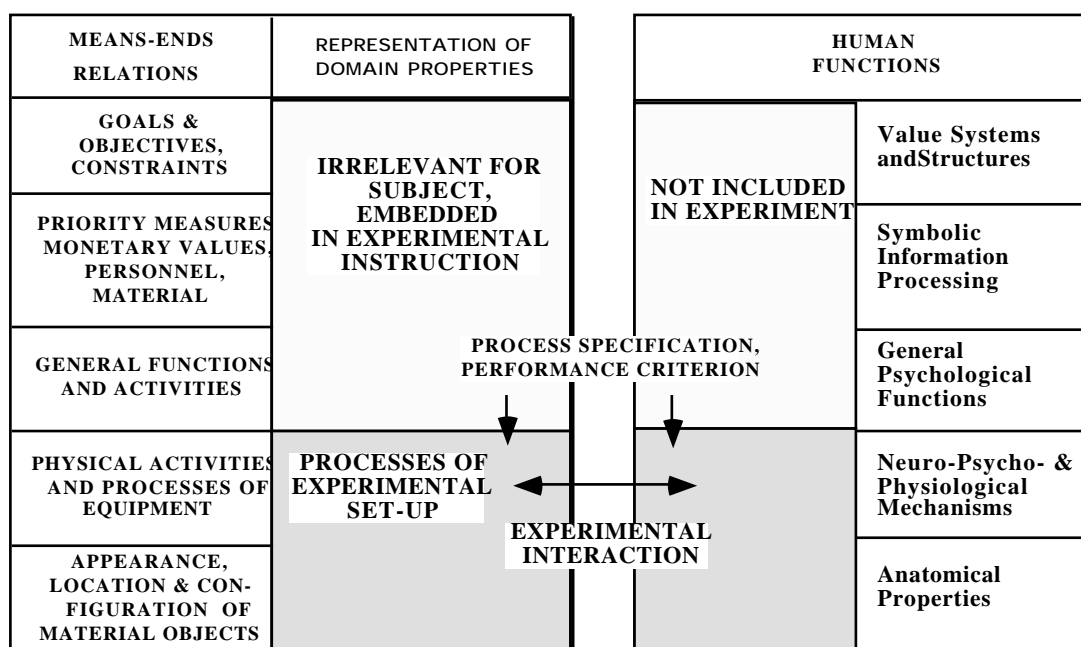


Figure 32. The context of experiments to measure characteristics of separate psychological mechanisms. The figure illustrates the means-ends levels of the experimental set-up including the actual functioning of the equipment with the overlay of the experimental ‘cover story.’ In a similar way, the mechanisms brought to work by the subject is arranged in a means-ends hierarchy. The hatched areas indicate those parts of the mechanisms which are within the experimental scenario, the rest are implicit constraints. The interpretation by the subject of the higher levels of the work domain (and the mechanisms of the set-up) is, e.g., blocked by the instruction, the experiment has no ‘meaning’ to the subject.

Examples are experiments to selectively measure speed, accuracy and signal-to-noise ratio in motor control; capacity of working memory span; etc. Experiments for this purpose are based on carefully selected and well controlled experimental tasks which selectively stress the application of particular psychological mechanisms. For such purposes, experimental tasks are normally artificial and have special research related labels such as, e.g., tracking task, dual choice task, etc. The instruction of the task *procedure* is very

explicit, i.e., the particular process to be applied in the experiment is clearly instructed together with a process-related criterion, e.g., related to speed or accuracy. In effect, consideration of all higher level functions, goals, and priorities is excluded by the instruction, only the lowest levels of the means-ends hierarchy are relevant for the subject, see figure 32.

Influence of Task Parameters on Performance

Examples are studies of e.g., task complexity, interface representation, feedback information delays, etc. on task performance. Such experiments are normally made in more complex task environments than the experiments just mentioned in order to have the necessary variability. Therefore, laboratory tasks are frequently designed to mimic actual work situation in process control, forest fire fighting, hospital diagnosis, etc.

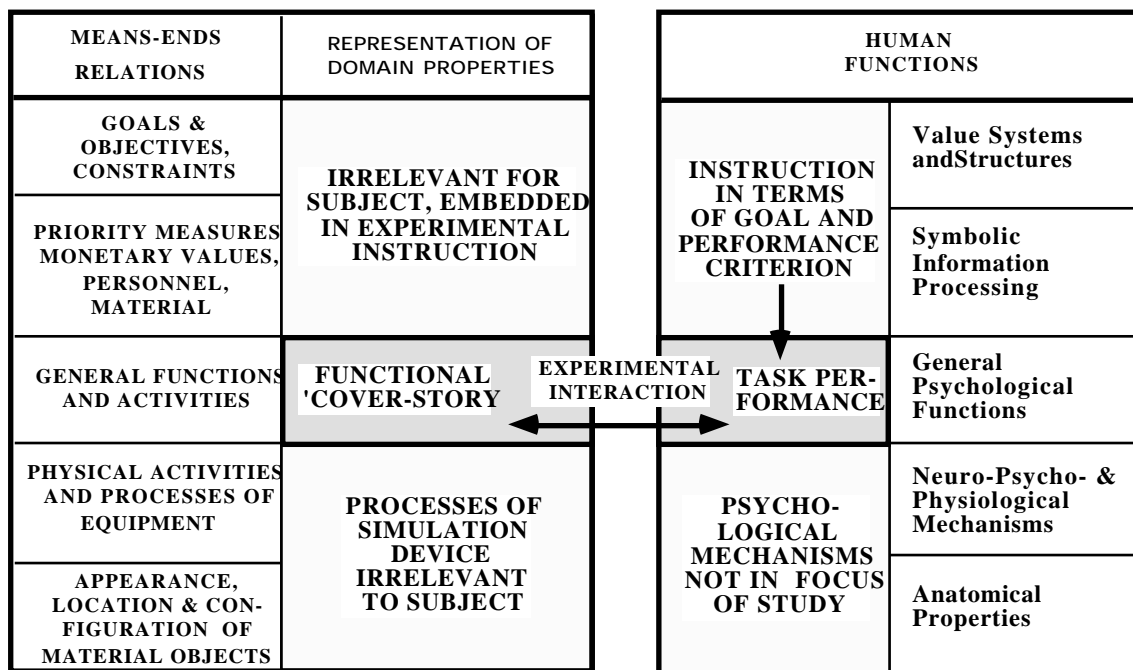


Figure 33. In other types of experiments, not only performance limits of mechanisms are explored, but dependence of the task performance and quality on task parameters. Results are typically expressed in task terms depending on task parameters, irrespective of mental strategy or psychological mechanism applied.

In such experiments, the goal and the function of the subject (rather than the work procedure) is explicitly formulated and the subjects correspondingly instructed, see figure 33. The results are typically generalized in terms of the relationship between controlled task parameters and performance in terms of quality, efficiency or reliability. One typical problem is, that the experimental setting activates other psychological mechanisms than the actual task of the cover-story. A frequently cited example is the question whether study of diagnostic performance by the social judgement paradigm in laboratory setting actually is relevant for expert performance in the field (see table 1 and Rasmussen, 1990).

Table 1: Medical Diagnosis		
Dimension of Analysis	Source Context: Hospital	Research Context: Psychological Laboratory of the Social Judgement Paradigm
Work Domain	<p><i>Goals:</i> Help to other person,</p> <p><i>Constraints:</i> Cost of errors can be high and will display bad judgement to colleagues.</p> <p><i>Priority Measure:</i> Efficiency, safety</p> <p><i>Function:</i> Diagnosis is integrated part of a complex set of patient treatments, research related functions and social care functions.</p> <p><i>Process:</i> Implementation of this function involves a large number of cognitive processes together with physical activities involving manipulation of the patient, tools, equipment, other people, etc.</p> <p><i>Physical environment:</i> A physical patient in a complex hospital environment</p>	<p><i>Goals:</i> To satisfy experimenter, to fit well into the social situation.</p> <p><i>Constraints:</i> Cost of errors low.</p> <p><i>Priority Measure:</i> To do well.</p> <p><i>Function:</i> Response to questions or questionnaires in order to satisfy the interviewer or experiment manager</p> <p><i>Process:</i> memory recall, and intuitive judgment only supported by paper and pencil.</p> <p><i>Physical environment:</i> A laboratory or office environment without immediate relationship to the task mimicked by experiment</p>
Task Situation	Diagnosis embedded in turbulent environment involving several other people. Diagnostic task is heavily dependent on the question to answer i.e., on the stage of the treatment plan.	Relaxed response to isolated questions of experimenter
Decision Task	Data collection, situation analysis, priority judgement, and planning of treatment are intimately interrelated as part of continued interaction with the patients	Isolated multiple attribute judgement task;
Mental Strategies	A large repertoire of mental strategies is available to the agent, including context based recognition,	The repertoire of relevant strategies is constrained by the situation; Useful are, in particular, strategies such as decision table look-up and recall of textbook material;
Agent Definition	Agent is identified as one of a set of cooperating agents sharing task and responsibility according to dynamically changing criteria;	Agent is isolated from the social context of the mimicked task;
Role Allocation	Depend dynamically on the context;	Static, well defined;
Social Organization	Task force depending on collective memory	Two person game

Agent Competency and Performance Criteria	Performance is depending on situation related intuition, i.e., on tacit knowledge; it depends very much on recognition skills and prior experience.	Only part of the agent's professional competency relevant. Recall of text-book decision-table kind of knowledge vital;
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Identification of Strategies, Heuristics, and Mental Models

The ambiguity of the experiments concerning the relationships between performance and task characteristics can only be resolved when analysis is focused on the mental strategies brought to action by agents for particular mental tasks such as situation assessment, diagnosis, or planning. For such experiments, simulated tasks are frequently used in the laboratory, mimicking in a controlled way a task known from normal work context (electronic trouble shooting studied by means of computer generated networks of interrelated nodes, medical diagnosis cases presented in paper-and-pencil representation, etc.).

In such experiments, the instruction is frequently phrased with reference to an actual task and professional subjects are used for the experiments. Results are, unfortunately, often generalized in terms of performance in actual work. It is, however, possible to generalize and to identify strategies with reference to basic cognitive processes and resource requirements, if a consistent taxonomy is used to interpret and compare the source and the research domains, as discussed in figure 31.

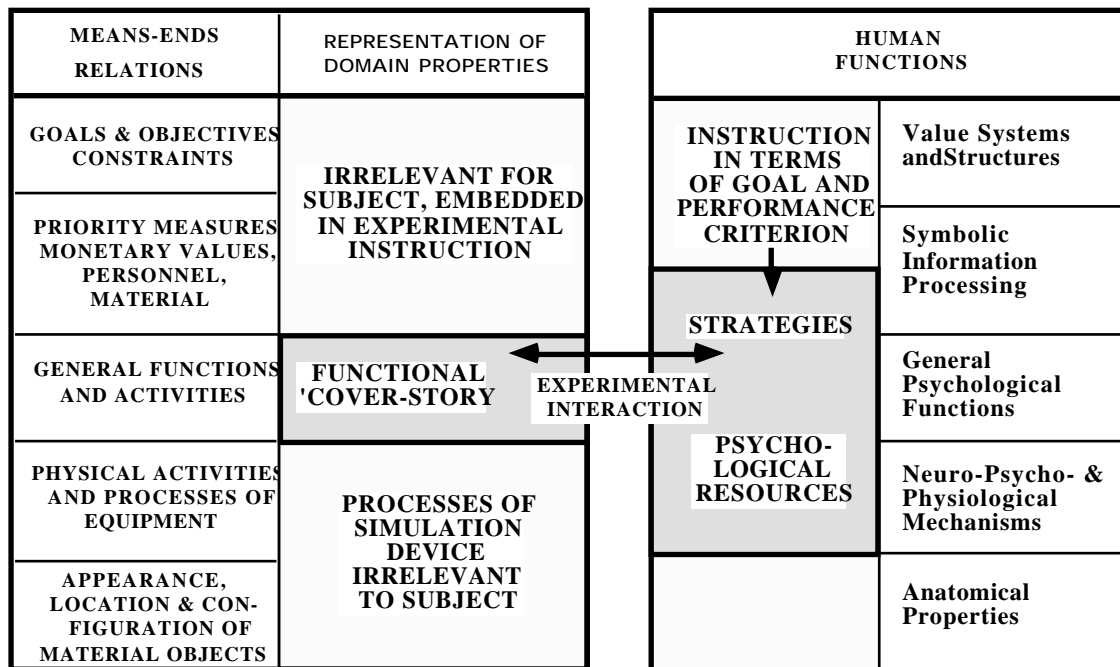


Figure 34. The experimental setting is similar to that of figure 3, but analysis is focused on identification of mental strategies in terms of basic cognitive processes.

Analysis of Problem Solving Behaviour in Complex Experimental Domains.

Such experiments are aimed at a study of the performance of subjects in exploration of a problem domain, their formulation of the problem they face, the goal they adopt, and the solution they generate. In this case, the instruction of the subjects cannot make explicit the goal of the experimental task, neither the experimental task procedure since the study of the formulation by the subject is the central experimental objective. Consequently, the instruction is frequently very open and given by a description of a ‘cover story,’ i.e., a description of an actual work situation which has been the source of the simulated relational, functional network, see figure 35. Results are often formulated with reference to performance in the simulated domain, even some groups (e.g., Doerner’s simulation studies of complex decision making) aim at an identification of mental strategies with reference to cognitive processes.

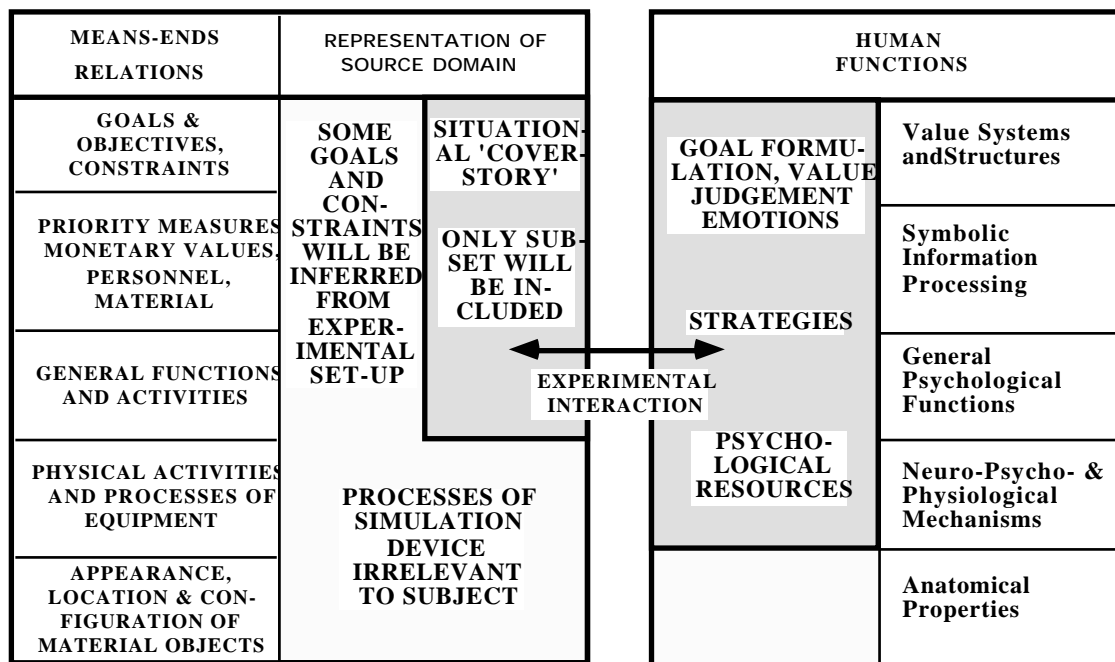


Figure 35. Illustrates the domain representation and relevance in experiments with decision making in complex work scenarios.

When computers are used to simulate complex scenarios from real-life work context, naive subjects (e.g., psychology department students) or professional agents from the particular work domain are asked to cope with tasks in this environment. In this case it is very difficult to control reliably the actual goals and performance criteria adopted by the subjects. It is, of course, the intention to keep the higher functional properties of the task, the working goals and subject priorities as undisturbed as possible but it should be realized that the physical process and anatomy of the real work domain are replaced by the processes and anatomy of the computer installation, see figure 5. Typically, a subject will be well aware of this fact, in particular when “in trouble”. It is often found, that a subject

will explain unexpected simulator performance by program inadequacies or bugs. In an actual work environment, there is a very subtle, many-to-many relationship between the goals, the functional level and the possible implementations at the physical process level and it will be very difficult for a subject to judge what is and what is not included in the simulation. The subject will, therefore, have to infer a number of goals, constraints, and functions from more or less intuitive assumptions about the task as conceived by the designer of the experiment.

In this situation, it is important to be able to analyze and describe explicitly the actual source domain of the research hypothesis as well as the research domain selected under the assumption that human agents in any work domain are basically goal directed, adaptive organisms having several mental strategies at their disposal in each situation and choosing the actual strategy from context and situation dependent performance criteria. If we accept this basic assumption, we can only draw conclusions from selective experiments and simulations, if we explicitly can describe the similarities and differences between the actual behavior shaping constraints of the actual work conditions and of the experimental conditions.

Simulation of Cognitive Processes

Simulation of human performance can be implemented on several levels of abstraction, see figure 36. In the present era of cognitive science, information processing models in terms of production rule systems are prominent. In such models, psychological mechanisms are implicitly represented in terms of capacity limits for performing the information processes involved. If however, the adaptive and learning abilities are in focus of investigation, simulation models which explicitly represent ‘psychological primitives’ are becoming interesting approaches (Reason’s models based on similarity matching and frequency gambling). Furthermore, when interest is focused on performance for which tacit knowledge, context and intuition are important features, explicit representation of the parallel processing, distributed features of the neural network becomes important. This has been attempted in the neural-network, connectionist approach, and in the use of optimal control theory applied for differential equation representation of pilot performance in dynamic vehicle control.

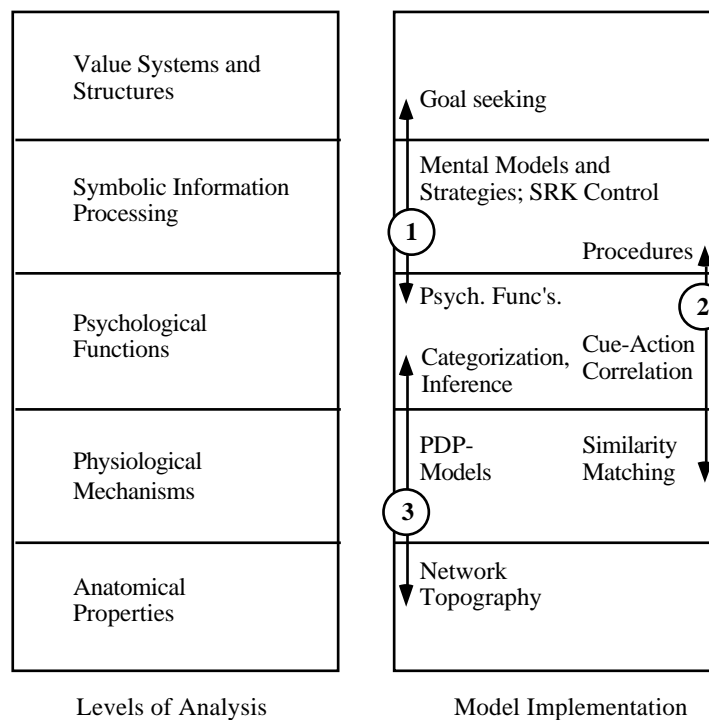


Figure 36. Simulation of human performance can be developed at several levels of psychological and cognitive processes. Information processing models (1) are focused on information processing strategies expressed in terms of basic cognitive information processes and mental models, i.e., production rules for operation on mental representations. Psychological mechanisms are basically considered to be able to formulate processing limitations. Other models are focusing on elementary psychological mechanisms (2), such as Reason’s psychological primitives, similarity matching and frequency gambling. Task procedures are formed by empirical cue-action correlatives, i.e., the model can generate production rules. Recently, models have been fashionable mimicking the processes of the distributed, parallel processing of the neural anatomy (3).

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Appendix:

An Example: Activities of Fighter Pilots

In order to demonstrate that a cognitive task analysis often quite naturally will be structured around the concepts discussed in the previous sections, the results of Amalberti's (1990) analysis of the activities of fighter pilots are reproduced below. The comparison show great similarity between the French and the Risø approaches to cognitive activity analysis in an actual case, even if some differences have been found in general, conceptual discussions.

1. Work Domain, Task Space

MEANS-ENDS RELATIONS	Means-Ends Structure
Goals and Purposes, Constraints.	Career, Reputation, Personal Safety, Care for craft, Impact on enemy, etc.
Priority Measures; Flow and Accumulation of Mass, Energy, Information, People, and Money.	Probability of attack, timing of trajectory, flow and inventory of fuel, of ammunition, etc.
General Functions and Activities.	Planning mission; Executing mission: Flying: navigation, vehicle control, system and automation management; Fighting: attack, evade threat from enemy and own forces
Physical Processes in Work and Equipment.	Use of instruments, manipulate controls, weapons, program computer
Appearance, Location, and Configuration of Material Objects.	See description of topography of work domain and inventory of relevant objects in figure 2 of this appendix

Figure A-1. List of the items mentioned in Amalberti's verbal description of the fighter pilot task during mission is here arranged in the abstraction hierarchy.

2. Delimitation of Work Situation

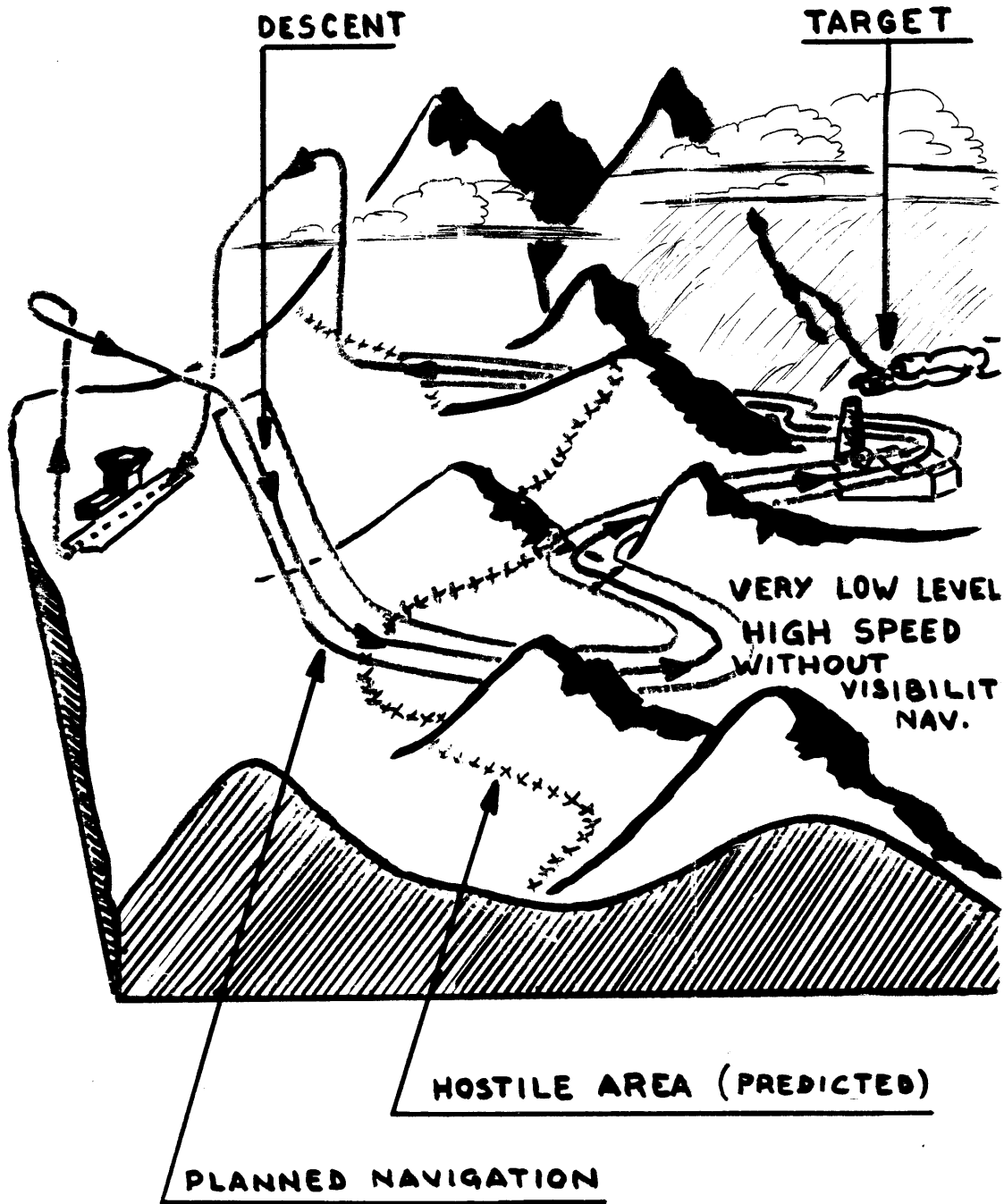


Figure A-2. Decision situation of the pilots in Amalberti's study. The decision task is embedded in a vehicle control task which is represented in the figure within the physical topography of the work domain. In vehicle control, the task requirements are intimately related to properties of the work domain topography, i.e., the skilled movement control is integrated with the higher level decision making. This is not the case in many other types of task in which interface manipulation and cognitive tasks are separated.

Activity Described in Domain Terms

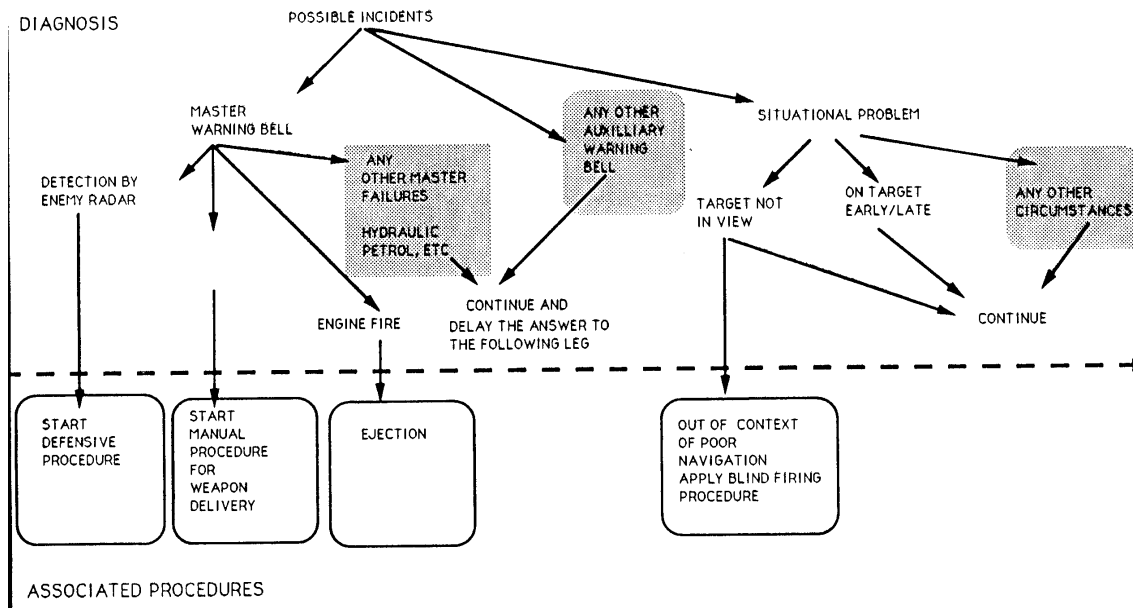


Figure A-3. A particular task situation of Amalberti's pilots described in terms of the work domain.

3. Analysis of Decision Task in Information Terms

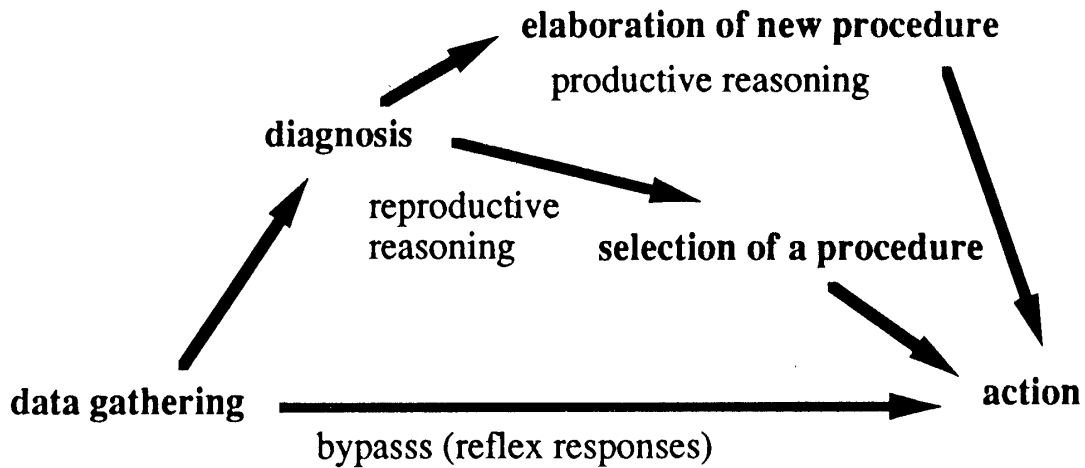


Figure A-4. This representation by Amalberti of the pilots' decision task, i.e., situation analysis and planning, is formulated in the same information processing dimension as the 'decision ladder' shown figure 21 of the taxonomy, and includes similar short-cuts of the elements of analytical decision making by an expert. One central conclusion of Amalberti's analysis has been that in *fast process control* the diagnostic task cannot be separated from the control task. This has also been the conclusion from chemical process control studies and medical diagnosis, as it is demonstrated in figure 22. This is a quality of the diagnosis in a control or therapeutic task in general, not just *rapid* control tasks such as piloting fighters.

4. Information Processing Strategies

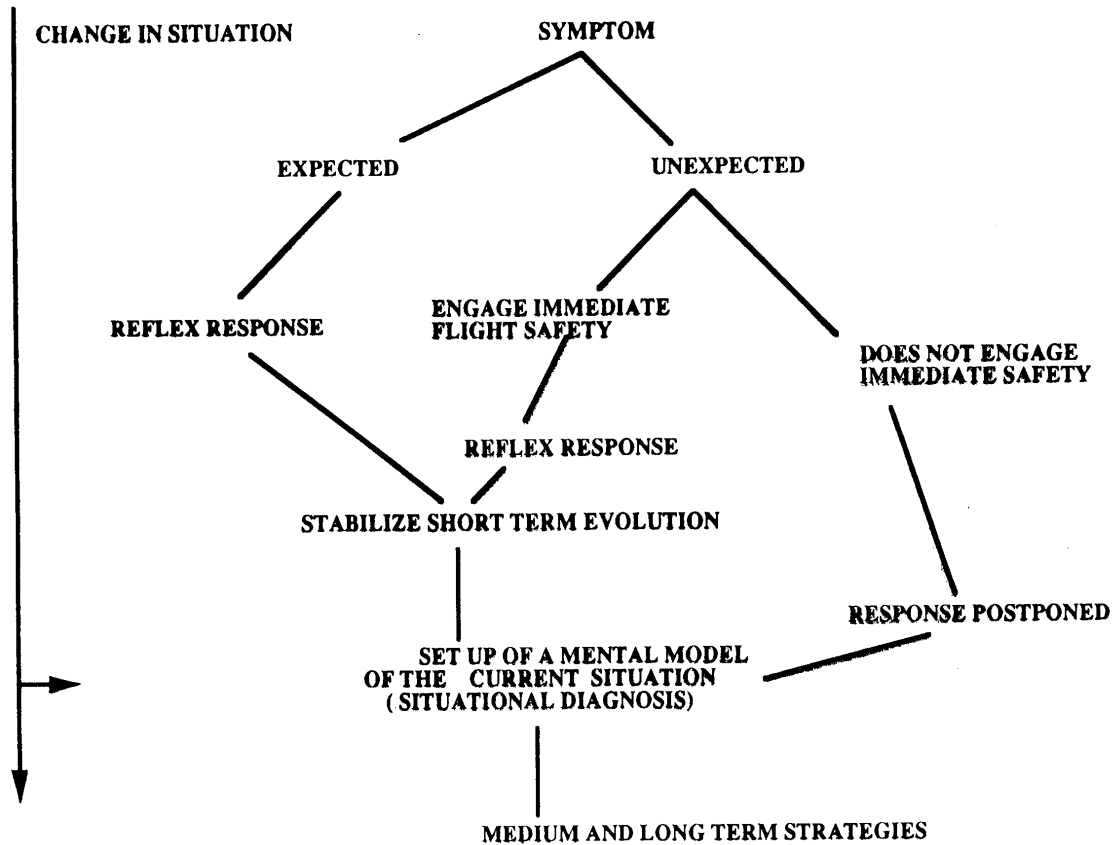


Figure A-5 illustrates Amalberti's analysis of different mental strategies which can be used by pilots, depending on the familiarity of the situation. Compare with the strategies discussed in section 4 of the taxonomy. Implicit in the figure is a distinction between different cognitive levels of control similar to the distinction in section 7 of the taxonomy.

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Abstract

The taxonomy is a conceptual framework for analysis of cognitive activities as they actually unfold in a complex work situation. It has emerged through years of studies in process plants, electronic maintenance workshops, libraries, hospitals, and manufacturing companies. The present approach to a taxonomy is shaped by intention to create a tool that can serve the design of advanced information systems by making it possible to match system properties to the users' actual, cognitive activities, resources, and preferences and to predict the kind of changes to be expected in the behavior of individuals and organizations in response to new information systems.

The taxonomy is, however, also intended to serve needs of research in general in complex work environments. In particular, it is intended to be a vehicle for generalization of results of field studies in various domains so as to make it possible to transfer results among domains.

Accordingly, the taxonomy is shaped as a multi-facet description system along the dimensions of 1) The work domain representation; 2) Activity analysis in domain terms; 3) Activity analysis in decision making terms; 4) Information processing strategies; 5) Actual work organization, the dynamic division and distribution of activities and their coordination; 6) Social organization and management styles and, finally, 7) Cognitive control of activities, the mental resources and preferences of the actors.

The report gives a description of the concepts used for analysis along these dimensions and, in addition, presents some examples for its application for comparison of field analysis and laboratory experiments.

The paper is a working paper and will be revised and up-dated from the experience gained from further field studies and system design projects.

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