

HCI PERSPECTIVES ON MAN-MACHINE SYSTEMS

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ABSTRACT

This paper, the revision of an earlier report by the same author (issued by the Department of Computer Science, Tampere University, Finland), discusses difficulties in the design of man-machine systems, from the perspective of human-computer interaction. In particular, a current approach to complex systems, called 'cognitive engineering', is detailed and discussed in relation to problems of complexity and representation. Some of the conceptual insights of Jens Rasmussen are considered, in addition to other design responses, as means of making progress in the design of better man-machine systems.

1. Perspectives on HCI

Following Rasmussen (Rasmussen, 1987; Rasmussen, 1988), we may distinguish three perspectives on human-computer interaction (HCI). The first of these concentrates on 'surface' characteristics of the interaction between computer system and user, seeking to optimise such interface features as response time, font size, display colours, shape and size of menus, icons, etc. (e.g. Miller, 1968; Davis and Swezey, 1983).

This approach has its basis in ergonomics - how people's performance at work is affected by variations in their environment - although the emphasis is on aspects of perception and motor skills. Invariably, this approach concentrates on experimental studies of human users interacting with computers and often seeks to establish general principles or guidelines for the format of interaction (e.g. Engel and Granda, 1975; see Alty, Mullin and Weir, 1987 for further bibliography). We might class this interest in HCI as an aspect of cognitive ergonomics.

A second perspective on HCI concerns itself with theoretical aspects of user performance, seeking to develop theories which account for the ways that users behave in their interaction with computer systems. These behavioural characteristics are usually discerned through experiments in cognitive ergonomics. Whereas the previous approach to HCI is concerned with optimising the interface characteristics of the interactive system, the present approach primarily seeks explanations for the affected user behaviour in terms of cognitive theory (e.g. Barnard, 1987) or in terms of the cognitive complexity of the interface system (e.g. Kieras and Polson, 1985; Vossen, Sitter and Zeigler, 1987). With its emphasis on the theoretical bases for users' interactive performance and often, models for cognition in HCI, this approach falls within the domain of cognitive psychology.

Our third approach to HCI also emphasises optimisation of the system interface, but is concerned less with low-level skills in the user. Rather, the aim is to maximise the degree to which the interface supports performance of the tasks which the user must accomplish via the interactive system. On this view, the ideal interface will present and elicit information in ways which best support the user or operator, though not merely from the viewpoint of his perceptual response. In particular, the presentation of system information should reflect the structure of the required user activities. This perspective on the nature of human-computer interaction is termed 'cognitive engineering', since it seeks to engineer the manner in which user and system interact, in order to design for optimum task performance (Rasmussen, 1988; Norman, 1986). This last approach, with its emphasis upon task support and design for minimum errors is our concern in the present paper.

As in all approaches to HCI, the designer of man-machine systems aims to achieve smooth and comfortable user interaction. Although interfaces to complex control systems should accommodate principles of cognitive ergonomics (i.e. well designed surface features), the designer's major concern must be support of the operator(s) in a manner which minimises operator errors. In order to appreciate the difficulties inherent in the design of such interactive systems, we must look in more detail at the nature of man-machine systems.

2. Man-Machine Systems

The sense in which I talk of 'man-machine systems', is somewhat restrictive. In most of the familiar things we do with computers, there is no example of man-machine systems. When word processing, or writing programs we engage in human-computer interaction across the software and hardware interfaces of a computer system. There is also a sense in which the computer acts as an intermediary between the user and a process he wishes to control (namely, writing the document or testing the program). But this does not constitute a man-machine system. A man-machine system differs from this in being directed at an on-going process or environment located externally to the computer system, but which falls under its control.

Obvious examples of such systems abound in process control domains such as electricity power generation, steel production, or chemical manufacture, but also include aircraft and vehicle systems where control is mediated by interactive computers. Significantly, the individual who interacts with such a computer system is generally called an 'operator', rather than a 'user'. The computer system used by such an operator is normally customised for the particular process, and so will include many built-in features (checks and safeguards) which make it appropriate for the application in question. Since the principal role for these computers is supervision and control of the process, they are often referred to as supervisory and control (S&C) systems.

In every such case, three features are minimally required to characterise a man-machine system:

- (i) an operator (or operators),
- (ii) a computer control system (S&C system),
- (iii) an external process to be controlled.

Note, however, that the external process is not itself part of the man-machine system. Rather, it serves as a focus for the joint efforts of the human operator and the computer control system.

2.1 Current Technology in Man-Machine Systems

Although most contemporary process control installations use colour visual display units (VDUs) to support interaction between operator and S&C system, bit-mapped screens are rare and there is still heavy reliance on mimic boards and annunciators for operator support. Mimic boards are usually extensive collections of instruments (dials, gauges, and symbols) which are laid out on a wall in the control room. Each item represents a particular part of the process, a valve, pump, turbine, or process sub-system, in a physical arrangement which reflects the dynamic relations they possess in the process itself. These display assemblies assist operators by providing a constant overview picture of the major process measurements as well as the physical or functional relationship of the major components. In some cases, adjustments to control sub-systems, e.g., alteration of set-points, may be effected through such mimic boards.

Alarms are usually signalled by annunciators, either as ringing bells, klaxons or flashing lights. The tendency in process environments is to have alarms on as many of the individually significant plant components as possible, despite the resultant risk of alarm proliferation. Thus,

"In a plant designed by bringing together standard equipment and subsystems, the alarm system is typically the conglomeration of the warning signals which the individual suppliers consider important for the monitoring of the state of their piece (as the basis for performance guarantees).

Hundreds of alarm windows presenting the state of the individual physical parameters may overload the operators' information capacity during disturbances" (Rasmussen, 1986a, p.180).

Traditionally, the operator is relied on to resolve any difficulties which arise in the process by means of his experience and by reference to the manuals on operational procedure. Input to the control system is normally through function keys with set-point adjusters for alterations to the operation of sub-system components. Notably, there has been little move toward direct manipulation of the control mechanics either through cursor control or touch sensitive displays.

Events such as Three-Mile Island and Chernobyl have encouraged a move toward more intelligent systems for process control: systems which will attempt to assist the operators in recovery from abnormal conditions as well as address some of the perennial causes of operator error. In what follows, we consider the respective roles of man and machine in the context of process control, with an eye to the design of improved man-machine systems.

3. Design Requirements and Obstacles

In a man-machine system the computer serves as an intermediary between the operator and the process. All tasks required of the operator are either checks or actions on the process, and to this end the control system provides the vital link between operator and process. Clearly, if the control system is to optimise the operator's activities it should reflect knowledge of the process in the support that it offers. Furthermore, the support system should perform with knowledge of the operator and his likely objectives, in order to hone its performance to such goals.

This characterises an ideal interactive control system in which the responsive HCI design embraces an understanding both of the process and the operator. But there are obstacles to the design of such systems. Before looking at the difficulties inherent in attaining such knowledge, we should consider the type of support most required by process operators.

3.1 Cognitive Support

The rapid growth in size and complexity of process control systems has progressively moved the role of the operator from manual tasks to those of planning and supervision. The trend towards 'automation wherever possible' has removed the more easily performed aspects of operator control to the automation. Ironically, this results in a constant increase in operator load, since he performs less at the 'skill-based' level, where he can automatically respond with a required action, and increasingly at the 'cognitive' level, where he must constantly assimilate and evaluate information on the state of the process, and relate this to his control objectives (plans for the process).

With the easier aspects of an operator's tasks likely to be ceded to the automation, the tasks which remain are the less tractable features in which human beings tend to excel over machines. These are often the tasks which require judgment, experience and interpretation on the part of the human. As the proportion of these demands swells, so process operators are subject to increasing cognitive workload.

This may not appear to be a problem in itself, but evidence suggests that many of the serious accidents which occur in process environments arise because operators misinterpret the state of the system. Since the operator's ability to interpret the state and potential of the process depend upon his own information processing capacities, the design of the interactive control systems should support this processing and so ease the operator's cognitive load.

3.2 Cognitive versus Ergonomic Support

An example may serve to clarify the nature of cognitive support, particularly in contrast to ergonomic support. An electronic calculator provides cognitive support for anyone wishing to perform arithmetic or other mathematical transformations. The support is cognitive because the user is relieved of remembering numerical values from intermediate steps in the calculation, and he is unburdened of the need to know and recall the calculation procedures themselves. In contrast, the degree of ergonomic support afforded by a calculator is minimal when compared to

the default of working with pencil and paper. Put crudely, ergonomic support makes it easier to perform tasks which require physical effort, while cognitive support eases tasks requiring mental effort. In the realm of man-machine systems, cognitive load can be lightened by assisting operators to meet demands on their memory, attention and planning.

The design optimisation for cognitive support may take the form of increased intelligence within the operator interface to the control system. This can help the operator by providing relevant interpretation of process data or by intelligent presentation of information across this man-machine interface. A facility such as intelligent alarm-handling, for example, can greatly ease the strain on the operator by filtering out superfluous alarm signals, and focussing attention on more severe aspects in the situation.

4. Understanding the Process and the Operator

One might assume that greater operator support may be achieved through a more complete understanding of the process being controlled. If we can fully accommodate the intricacies of the domain then the required control should be possible at all times. This is naive. In the first place, there may be a false assumption that the process to be controlled constitutes a closed system, responsive only to a manageable range of variables. In reality, most processes are not closed systems but subject to influence from rogue 'external' factors. As a result, there is rarely any fool-proof way of allowing for all possible spanners in the works.

What is more, having a closed process will not remove all control problems. The possibility of 'external' influences is only one obstacle to full comprehension. A greater barrier is the conceptual complexity inherent in the way in which we interpret and relate process events. Just as in any other realm of knowledge, our understanding is founded upon a hierarchy of interrelated concepts. To have a complete grasp of any process domain is to do more than remove unpredictable factors. It requires a mastery of how all relevant concepts in the domain interrelate and this requires that we are able to identify and isolate those pertinent concepts. Even if we successfully delineate a closed physical domain, it may be impossible to secure a corresponding closed conceptual domain.

Clearly, the conceptual apparatus that is brought to bear when the control system is designed should be capable of supporting the operator in his understanding of process behaviour. In particular, the range of possible interaction across the man-machine interface should enable the operator both to comprehend the process state and derive appropriate control actions. This presents problems of conceptual complexity by virtue of the different ways in which operator and process behaviour may be understood.

4.1 Levels of Abstraction

Rasmussen (1983), distinguishes five levels of abstraction (developed from the analysis of verbal protocols in the fields of computer maintenance and process control). These vary from the 'lowest' conceptual level of physical form, through physical functions, generalised functions and abstract function, to functional purpose at the most abstract (see Figure 1, below).

These descriptions represent different levels of abstraction and decomposition which a human operator may use to cope with the complexity of a technical system (Rasmussen and Goodstein, 1985). Movement from one level in the hierarchy to a higher level is not merely a removal of information detail, but an addition of information on higher level principles which govern the way that elements at the lower level interact. Movement through the abstraction hierarchy reflects the agent's comprehension of the system and its requirements. In consequence, adequate decision support (and similarly, adequate design) must be capable of accommodating this complexity of representation.

In these levels of abstraction we have the nub of a representation problem. Although it seems evident that operators will employ such abstractions in their attempts to comprehend the process domain, the precise contents to these abstractions are far from obvious. There may be few difficulties in establishing a representation of the physical structures in the man-machine system but this will be less than adequate for a full grasp of the system performance, especially since

operators naturally adopt a goal-driven, rather than technology-driven, approach to system control.

Likewise, in the use of any such system, the representations afforded to the operator will determine the ease with which he can formulate and hence accomplish any of his objectives. The potential complexity of man-machine systems and the variety of possible task representations, create major difficulties for design. Thus,

"great care should be taken when a computer is used to generate task specific displays in order to match the representation used for displays to the operator's preferred work strategies and understandings to the processes. If this match is not successful operators may be left with the more complex situation of having to evaluate the information processes of the computer" (Rasmussen and Lind, 1981).

4.2 Levels of Behaviour

Rasmussen's levels of abstraction illustrate one aspect of the necessary richness and complexity of representation required for comprehension in process control. Clearly, this is an obstacle to the design of man-machine systems, because the support system's capacity to interpolate the operator's aims and interests in the process is grounded upon the appropriateness of its representation of the process domain on the one hand, and the operator's objectives on the other. Yet, this is not the only representational issue.

The avoidance of operator errors will also depend upon the system's ability to make sense of the operator's behaviour. This in itself has a complexity which goes beyond the levels of abstraction mentioned above. We can characterise three types of behavioural performance: skill-based, rule-based and knowledge-based (Rasmussen, 1983, p.258). The basis for this categorisation is the differing aspects of information processing that are typically involved in different modes of behaviour. Thus, skill-based performance takes place 'without conscious control as smooth, automated, and highly integrated patterns of behavior' (op. cit.). This category includes 'continuous integrated' behaviour such as riding a bicycle or playing a piece of music. Such behaviour is typified by responses that have been 'learned', and can be performed 'automatically' at the occurrence of an appropriate signal or cue.

FUNCTIONAL PURPOSE

Production flow models,
System objectives,
constraints, etc.

ABSTRACT FUNCTION

Causal structure: mass,
energy and information flow,
etc.

GENERALISED FUNCTIONS

"Standard" functions and
processes: feedback loops,
heat transfer, etc.

PHYSICAL FUNCTIONS

Electrical, mechanical,
chemical, processes of
components and equipment.

PHYSICAL FORM

Physical appearance and
anatomy; material and form;
locations, etc.

**REASONS
for proper function,
requirements,
PURPOSE BASIS.**



**PHYSICAL BASIS
capabilities, resources,
causes of malfunction.**

FIGURE 1 : LEVELS OF ABSTRACTION (from Rasmussen, 1986)

Rule-based behaviour is characterised by control via some 'stored rule' or procedure. Such performances are goal directed, although the goal may be 'found implicitly in the situation releasing the stored rule' (p. 259). Examples of such activity would include deliberate behaviour such as that exhibited in learning a control task. Such rule-based performances are usually 'based on explicit know-how, and the rules can be reported by the person' (op. cit). Such behaviour involves the interpretation of signs in the environment which signify the appropriateness of the applied rule.

A third variety of behaviour, knowledge-based, is typically employed in circumstances where no stored rules are available. In this case, there is an explicit goal and a plan is evolved for pursuit

of this objective. Here, individuals generate hypotheses for their situation as a basis for action, in pursuit of their goal. Such behaviour relies upon the operator's understanding or "mental model" of the current context and his interpretation of symbols, as having significance in relation to his mental model. These three aspects of behaviour characterised by Rasmussen, are represented in Figure 2, below.

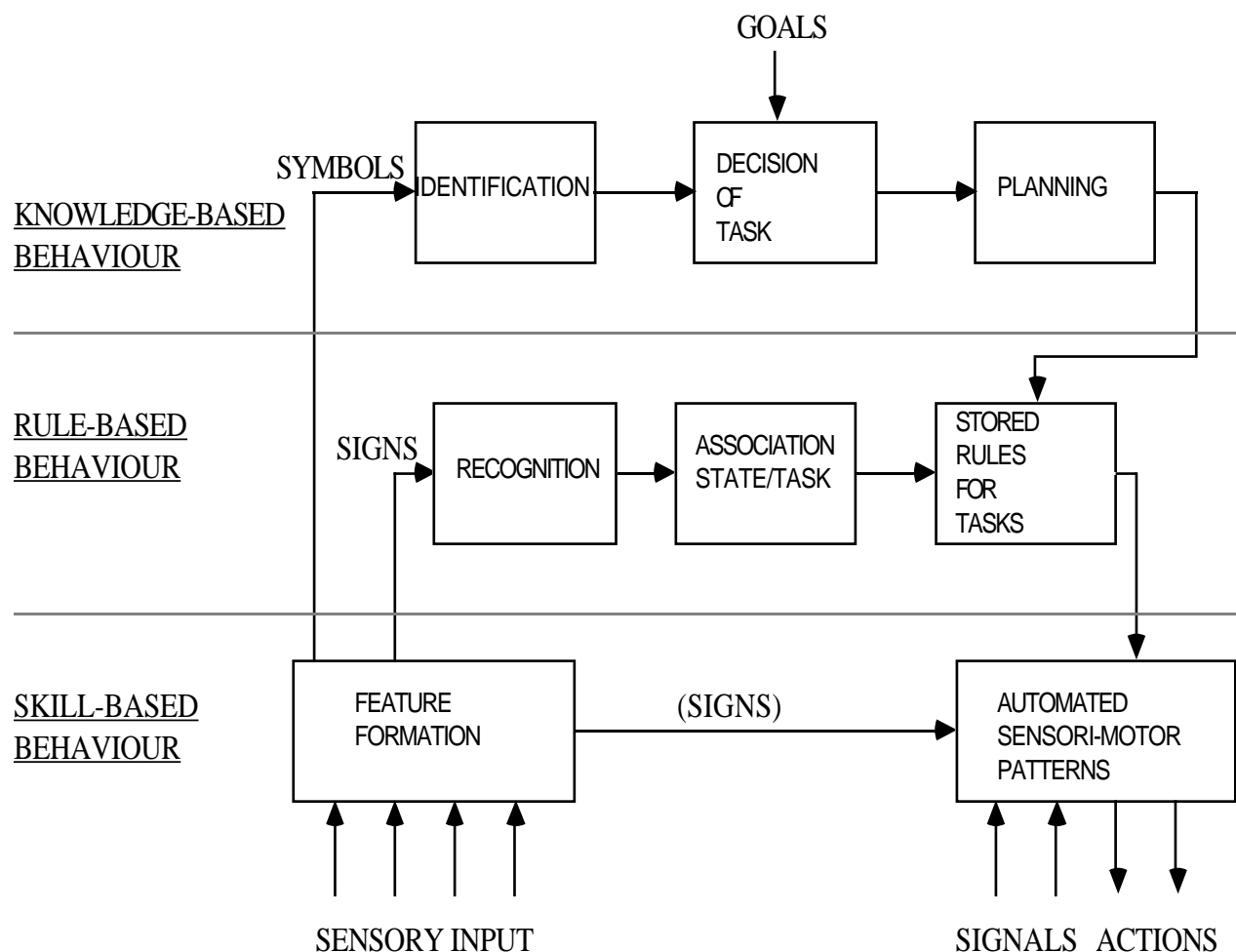


FIGURE 2 : RASMUSSEN'S LEVELS OF BEHAVIOUR
(from Goodstein et al, 1988)

The significance of these levels of behaviour is firstly, in illustration of the different modes under which human beings may operate. For this reason, it is no simple goal to anticipate possible human responses to the performance of specific tasks. Progress in matching task requirements to agent performance must take account of the behavioural (or cognitive) complexities which may arise.

The possibility of behaviour at these different levels of cognitive activity also provides a schema for characterising situations in which operators may require cognitive support. Thus, if tendencies toward skill-based responses are identified as potentially dangerous, support may be provided to reinforce behaviour at the rule-based level. Furthermore, the need to build systems which are capable of operator support in unforeseen situations translates into the need for support at the level of knowledge-based behaviour.

While Rasmussen's characterisation does not provide phenomenological criteria for identifying instances of each type of behaviour it does yield insight on their significant cognitive aspects. Thereby, it enables us to better articulate the cognitive requirements for operator support and helps to identify the aspects of behaviour which may be most in need of support. Figure 3 illustrates the mapping between operator tasks and levels of behaviour (from Stasson, Johannsen and Moray, 1988).

	manual control	interpreting monitoring	teaching	fault management	planning
knowledge-based	-	*	-	**	**
rule-based	*	**	**	*	*
skill-based	**	*	*	*	-

FIGURE 3 : LEVELS OF BEHAVIOUR AGAINST OPERATOR TASKS

4.3 Decision Making

Rasmussen's five levels of abstraction represent the problem space for operators in a complex domain. With this in mind, and building upon his classification of levels of behaviour, he has also developed a representation for decision-making. Portrayed as a step-ladder, decision-making proceeds upwards, in the phase of knowledge-based analysis, through observation and identification, to interpretation and evaluation. Then, downwards, in the phase of knowledge-based planning, through task definition and procedure formulation to action. Rule-based shortcuts are characterised across the ladder as pre-set responses, or learned cues (Rasmussen, 1986). This model was developed for describing operator's decision making but is also applicable as a basis for the design of system control strategies (Rasmussen & Lind, 1982).

5. Design Responses

The examples given above illustrate the complexity of incorporating adequate support knowledge within an intelligent interface for process control. Significantly, the trend is to aim for designs which can help operators get out of difficulties, even in situations which have not been envisaged, through support for their assessment of the situation and planning for recovery. This may require that we attend to features such as the acquisition and use of mental models. Certainly, the agent's behaviour, as well as that of the system being used, must be adequately represented for the domain in question. (The need for user models and a 'user image' for the system, is stressed by Hollnagel and Woods, 1983). In what follows, we consider some of the design responses which aim for such improvements in man-machine systems.

5.1 Joint Man-Machine Systems

As a move toward closer integration of man and machine it has been suggested that man-machine systems be construed as joint **cognitive** systems rather than as distinct entities (Hollnagel and Woods, 1983). A cognitive system is elucidated in the following terms:

"A cognitive system produces 'intelligent action', that is, its behavior is goal oriented, based upon symbol manipulation and uses knowledge of the world (heuristic knowledge) for guidance. Furthermore, a cognitive system is adaptive and able to view a problem in more than one way. A cognitive system operates using knowledge about itself and the environment, in sense that it is able to plan and modify its actions on the basis of that knowledge. It is thus not only data

driven but concept driven. Man is obviously a cognitive system. Machines are potentially if not actually, cognitive systems. An MMS [man-machine system] regarded as a whole is definitely a cognitive system" (op. cit., p.589).

Clearly, the cognitive nature of the human operator must be accommodated in the design of computer control systems. In task execution, the agent's goals and intentions can be regarded as psychological variables, which directly express the concerns of the operator. To perform a task, he must master the control of physical variables attached to the physical mechanisms of the application domain, thereby translating intentions into physical actions on the machine and interpreting physical variables in terms of psychological goals (Norman, 1986). Between the agent's goals and the physical system lies a gap which must be bridged by execution in one direction - goals to physical system, and by evaluation in the other direction - physical system to agent's goals. The system design process must aim for easy bridging between this realm of goals and the domain of the physical system.

If designers fail to acknowledge the importance of cognitive aspects in operator and system performance they may fall to the 'physicalist fallacy' of thinking that man can be described consistently and adequately in the purely physical terms of natural science (Hollnagel, 1983), and run the risk of building man-machine systems 'without a proper model that describes the relevant portion of the psychological world' (Hollnagel and Woods, 1983, p.586).

The recognition that human agents must be viewed as cognitive systems is a crucial step toward adequate design principles, but goes only part of the way. The central point emerging from Hollnagel and Woods' perspective is that the man-machine system should be regarded as a **single** cognitive system. Thereby, an overall appreciation may be achieved of the reciprocal roles of man and machine in terms of the cognitive processing contributions that each can make to the supervisory and control tasks. In Woods' words,

"The challenge for psychology is to provide models, data, and techniques to help designers to build effective configuration between human and machine elements of a joint cognitive system" (Woods, 1986, p.153).

Without an adequate 'cognitive coupling' of man and machine there is everpresent likelihood of misunderstandings on the part of the agent and a corresponding increase in risk of errors. Thus, for example, there is a real problem of data significance when large amounts of data have to be presented across a man-machine interface. 'Failures in this cognitive task are seen when critical information is not detected among the ambient data load, when critical information is not assembled from data distributed over time or over space; and when critical information is not looked for because of misunderstandings or erroneous assumptions' (op. cit. p. 162).

5.2 Cognitive Task Analysis

One strategy which may improve man-machine systems is the use of cognitive task analysis at the design stage. This would identify those cognitive demands arising from the supervision and control requirements of the process which must be met jointly by the operator and the control system. By incorporating these in the requirements analysis for the joint man-machine system it should be possible to design for practical resource allocation between the computer system and human operator. Thereby, an integrated design may be derived which best meets the demands of the process domain whilst also allowing for optimum operator support. Thus,

"Unless the control systems designer also identifies the set of information-processing strategies that will meet the control requirements, he will not be able to ask meaningful questions of cognitive science concerning human capabilities and preference for the interface design" (Rasmussen, 1986, pp.55-56).

Design generally begins from an account of the purpose and description of the process to be controlled and proceeds by a functional decomposition of the control requirements. For man-machine systems this should include the roles and functions both of the support system and the human operator, taking into account the demands of the domain itself. In doing this, we seek to account for the significant cognitive demands (information processing and decision-

making requirements) placed upon the operator by the tasks and the system in question. The role of CTA in design is characterised by Woods :

"Effective cognitive systems design requires, first, a problem-driven, rather than technology-driven approach. In a problem-driven approach, one tries to learn what makes for competence and/or incompetence in a domain (i.e. cognitive task analysis...) and then to use this knowledge to provide tools which help people function more expertly" (Woods, 1986, p.158).

Clearly, the recommended design procedure must embrace not merely the physical representation of the process domain but also the control requirements and the resources available for control. The manner in which decisions should be taken, in terms of staffing and standard practices, must also be considered since this may determine the availability of authorised personnel and hence, the possibility of major executive decisions.

Decision making requirements, as well as the operator's information processing needs, may be derived from the task and control requirements of the plant through an analysis of the means-end relations which obtain for the domain in question. One available technique is 'multilevel flow modelling' (Rasmussen and Lind, 1981; Lind, 1982; Lind, 1984). Multilevel Flow Modelling (MFM) is a technique for modelling dynamic systems using abstractions drawn from thermodynamics. The principal concepts are interrelated mass and energy flow structures and levels of physical aggregation. MFM provides one way of representing aspects of complexity and abstraction for technical systems and has found application in the construction of knowledge-based systems as well as in interface design for supervisory control systems.

In his discussion on system concepts and the design of interfaces for supervisory control (Lind, 1988), Lind stresses the importance of embodying means-end and whole-part relations in the design of information interfaces. The whole-part relations afford an organisation of system structures suitable for display hierarchies, while the means-end relations afford a way of organising system information in terms of goals and means for their achievement.

Alternative levels of description from the abstraction hierarchy are represented in MFM, which can describe both plant functions and system goals. The use of abstraction levels means that while a reference level describes the function of a plant subsystem - i.e., **what** is going on, the next level up describes **why** this function is required, and the level immediately below the reference level provides a description of **how** that plant function is established. This use of 'why, what and how' provides a systematic (function oriented) strategy for searching through information in the model and has also been used in the design of information display systems in conjunction with MFM (Goodstein, 1982).

The place for this means-end analysis in the design procedure is illustrated in Figure 4, below. This figure portrays Rasmussen's account of the required considerations and constraints which determine the efficacy of the final man-machine system.

6. DIALOGUE DESIGN

We have seen that the cognitive engineering perspective on human-computer interaction is especially relevant in the realm of man-machine systems. Obvious difficulties in achieving complete representations of process domains and operator's behaviour mean that design of supervision and control systems can at best, be extended to address the information processing and decision making needs of operators.

An emphasis upon man-machine systems as joint cognitive systems, engaged in a co-operative venture of supervision and control, helps to focus attention on the pragmatic factors which influence operator performance. On its own, however, this perspective does not generate a precise design methodology. Indeed, Hollnagel and Woods advocate this perspective as a setting within which the problems of design may better be addressed. 'Joint cognitive systems' is not represented as a design strategy in its own right, rather, it helps the designer to keep the combined cognitive requirements of man and machine, in mind. An

appropriate procedure for design, as portrayed by Hollnagel and Woods, is given in Figure 5, below.

Note that cognitive task analysis is seen as an essential step in the design process. In addition, Lind's 'multilevel flow modelling' is cited as a suitable method for performing the means-end analysis phase (Woods and Hollnagel, 1987).

We might conclude that the combination of Rasmussen's design insights, the joint cognitive systems perspective and cognitive task analysis go some way toward characterising a methodology for design in man-machine systems.

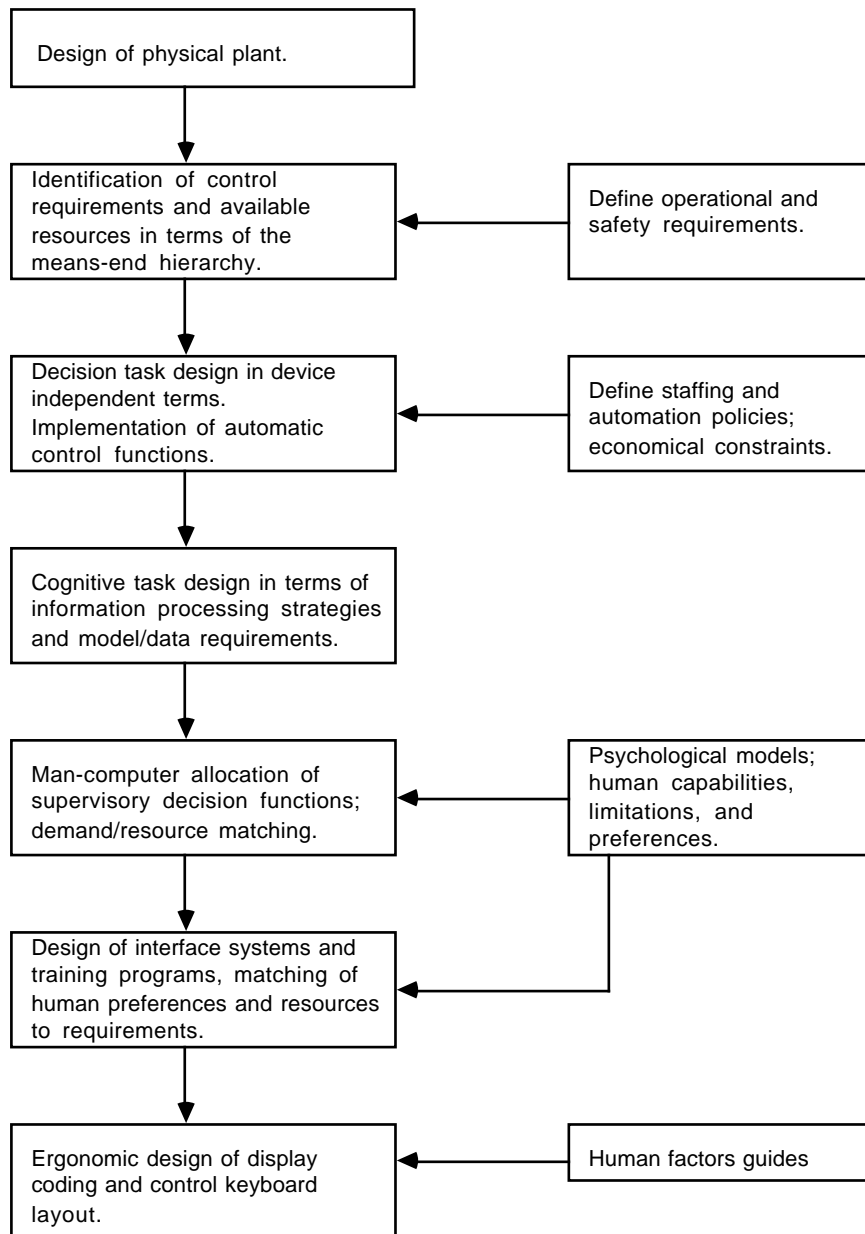


FIGURE 4 : Systematic Design of Supervisory Control Systems (from Rasmussen, 1986).

Yet there is a further viewpoint which meshes well with those already mentioned. Figure 6, below, shows the normal procedure for design of display systems for process plants. This is generally plant-based and proceeds bottom-up from a specification of the required icons (plant morphology), through the sequences of pictures (syntactic representation), to the binding of process variables (semantics) Being essentially plant-based, this methodology pays scant attention to the information needs specific to the tasks and supervision of the system.

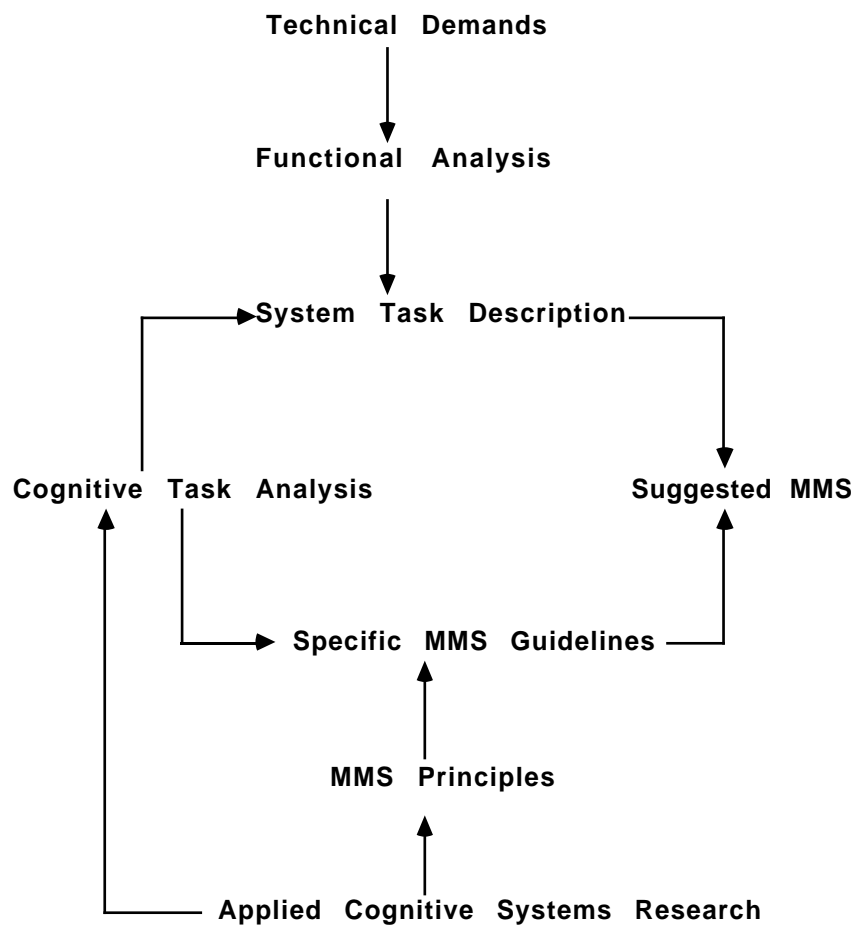
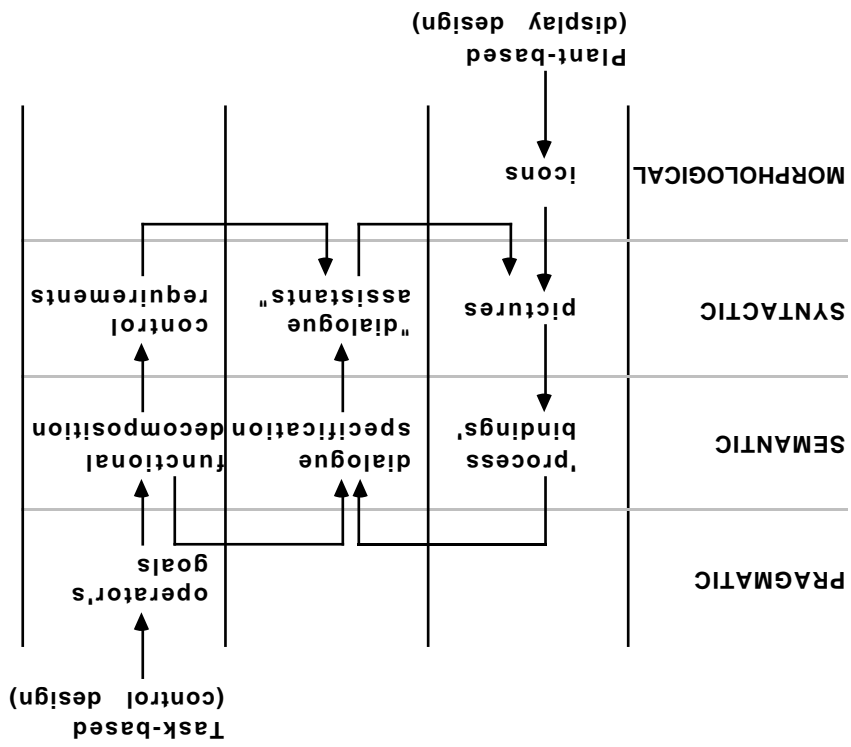


FIGURE 5 : COGNITIVE TASK ANALYSIS IN THE DESIGN PROCESS
(from Hollnagel and Woods, 1983)

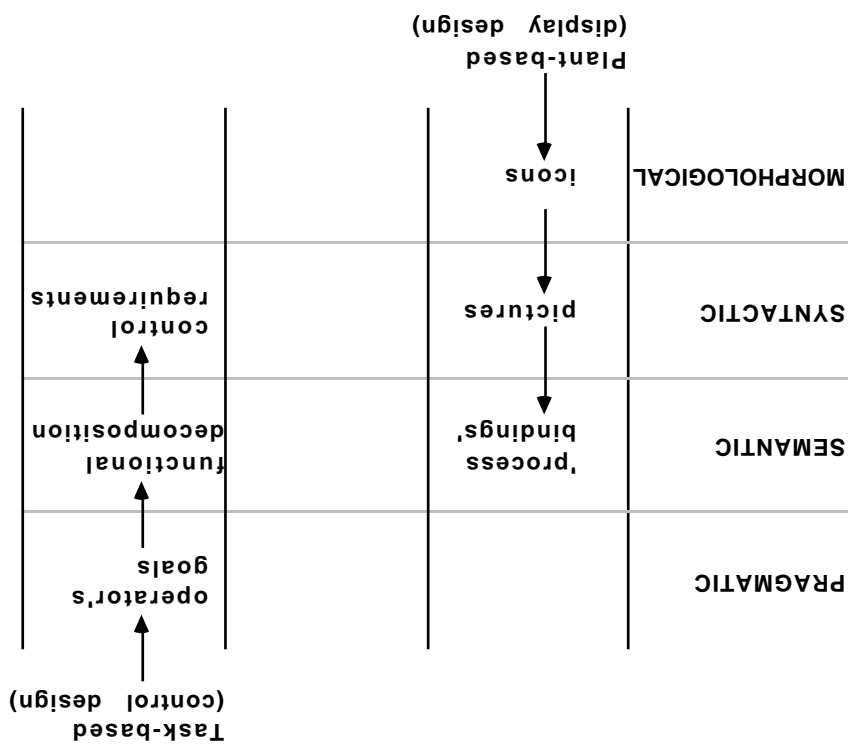
Figure 6 also shows the task-based methodology of conventional task analysis. This proceeds top-down from a consideration of the operator's and the system goals (the pragmatic level), through a functional decomposition (the semantic level) and possibly a cognitive task analysis, to control requirements (the syntactic level) which dictate the required physical control facilities.

FIGURE 7 : INTERACTION-BASED DIALOGUE DESIGN



Given our emphasis upon the cognitive engineering of such complex systems, it is clear that a unifying approach is required to bring together the otherwise complementary but disparate display-based and task-based methodologies. What is missing is an interaction or dialogue-centered aspect to the design (Hollnagel and Weir, 1988), which can accommodate the exigencies of both display-design and task-design.

FIGURE 6 : CONTRASTING DESIGN METHODOLOGIES



This can be achieved by means of a dialogue specification (at the semantic level), which provides a high-level description of the requirements on dialogue, and aims to unite the other two design constraints in an emphasis upon the interaction and information processing required of the operator (see Figure 7).

Figure 7, represents the synthesis of input from the task-based (control oriented) methodology and the plant-based (display oriented) methodology within the semantic level of dialogue design, in order to produce an appropriate specification of the required dialogue. This implementation of this specification - here, termed "Dialogue Assistants" - acts as a binding link between the control requirements and the picture representations of the process, at the syntactic level.

Such a specification technique is employed in the ESPRIT Gradient project (P857), which seeks to design advanced interface facilities for operator support in process control domains. The use of 'Dialogue Assistants', as the syntactic bearers of dialogue specification, is described in Alty and Mullin, 1987. Through such a device, the otherwise dissimilar constraints of display characteristics and task control requirements can be integrated thereby underlines the importance of human-computer interaction in the design of man-machine systems.

7. CONCLUDING REMARKS

The emphasis on interaction-based dialogue design helps to merge the interests of plant-based and task-based display and control design. Yet, beyond this, we must emphasise that the problems of complex system design, analysis and evaluation discussed above may best be appreciated from the viewpoint of cognitive engineering. Indeed, the central significance of cognitive engineering for the arena of complex systems cannot be overstated. Furthermore, Rasmussen's contributions are seminal, and their spur to others is evident from the current wealth of related research (cf. Goodstein et al, 1988).

In this context, we must view cognitive engineering as more than a perspective on HCI. It is rather 'a top-down approach to the analysis, design and evaluation of entire [complex] systems', in which the quality of human-computer interaction 'can only be judged with reference to the ultimate system goals and constraints such as productivity and safety' (op. cit. p.327). Thus, the distinctive characteristic of cognitive engineering, which gives a unifying perspective on the issues discussed in this paper, is its holistic approach to complex systems in which it seeks to account for aspects of user performance in relation to cognitive task requirements and the overall goals of the technical system.

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