Author version, published in: *International Journal of Industrial Ergonomics*, 8, pp. 345-361, 1991.

An approach towards the design of intelligent man-machine interfaces in process control

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Abstract

This paper is related to improvements carried out in the field of man-machine communication in complex industrial processes, using the concept of 'intelligent' interface. Following a review of literature on this subject, an 'intelligent' interface design based on ergonomical concepts is described. Finally, we present an approach to the design of an 'intelligent' interface. The Decisional Module of Imagery (D.M.I.) as it is called, is based on two models : a task model and a user model. The D.M.I.'s structure and its integration in an experimental platform are described in the last part of this paper.

Relevance to industry

Industrial processes are becoming more complex with the emphasis on production and safety. It is under such conditions, that the risk involving human error becomes more significant. This paper contributes to an 'intelligent' interface design that can be used in the field of process control. Its main goal is to improve the man-machine system reliability, and consequently productivity and safety.

Keywords

Ergonomics, 'intelligent' interface, process control, simulation, man-machine interface design, task analysis.

Introduction

The automation of complex industrial processes has led to installations which are almost totally autonomous during normal operation. However, where the control of an industrial process may be erroneous, a control system with an almost 'human presence' is desirable. The set of abnormal situations cannot be modelled and fault management is often based on human know-how. The human supervisor becomes the ultimate guarantor of the system's security when it is deficient.

To help operators when they perform their cognitive tasks, current research aims at integrating 'decision support tools' in process supervision and control systems. In such cases, the artificial intelligence approach seems to be attractive mainly for static systems (see for example the diagnostic approaches of De Kleer and Williams, 1987; Genesereth, 1984; Reiter, 1987). At present, new artificial intelligence techniques enable the dynamics of the process to be taken into account. They even allow for any anticipated interventions that would occur in the event of accident. The qualitative modelling techniques (see Caloud, 1988; Feray-Beaumont, 1989 and Kuipers, 1985) or dynamic knowledge and reasoning treatment methods (see Tang, 1989; Allen, 1985 or McDermott, 1982) should be noted.

These works along with new research trends are aimed at improving the ergonomics of man-machine interaction through better cooperation between human and decision support tools (Millot, 1988).

Primarily, our research concerns man-machine co-operation problems, and aims at optimising the information exchange between both the process, the assistance tools and the operator by using an 'intelligent' interface (Kolski et al., 1990). This paper is divided into four main parts: the first defines the concept of an 'intelligent' interface and reviews the different approaches found in literature. The second part describes an ergonomic method contributing to the design of 'intelligent' man-machine interfaces. The third part presents the author's approach, called D.M.I. (Decision Module of Imagery). The last part describes the experimental control and monitoring of a simulated process utilizing the D.M.I.

The concept of the ‘intelligent’ interface

The 'intelligent' interface concept is derived from many propositions found in literature and is used to describe advanced interfaces, or intelligent decision support systems which are in communication with a user interface management system, for instance:

• *Dynamic media concept* (Kay and Goldberg, 1977), which has led to object oriented interfaces such as SmallTalk.

• *Adaptive interface concepts* (Edmonds, 1981), where user dialogue modes must adapt themselves to the task that the user has to achieve. According to Norman (1979), such an intelligent system must be made self-aware through monitoring its actions, knowledge, requirements, goals and intentions. Rouse and his colleagues (Rouse, 1988; Rouse and Rouse, 1983; Rouse et al., 1988) and Hefley (1990) propose architectures and methods for designing adaptive interfaces and tools. Hefley (1990) presents a functional architecture, relying on user modelling, for adaptive intelligent systems oriented toward providing a collection of agents which monitor and mediate the interaction between the user and the application.

• *Flexible interface concept* (Williges et al., 1987). Here, the user can configure his interface according to personal subjective criteria - preferences in

• *Flexible interface concept* (Williges et al., 1987). In this case, the user can configure his interface according to personal subjective criteria : preference in presentation modes or interaction styles, and so on. presentation modes or interaction styles and so on.

• *Human error tolerant interface concept* (Rouse and Morris, 1985; Malvache, 1990). in general, this method 'consists of watching human operator activities in order to identify, using a human predictive model, actions which meet criteria such as safety. This approach replaces wrong actions with appropriate ones and relies on the principle that the operator, even when assisted by performance tools, remains prone to error. This work on the design of human error tolerant interfaces, is based on human operator reliability, which is the subject of many human error classification studies (De Keyser, 1980; Rasmussen, 1982; Rouse and Rouse, 1983; Leplat, 1985; Rasmussen and Vicente, 1987). Hollnagel (1989a), presents a system which provides detection of on-line erroneous actions. The system, called RESQ, is based on a combination of plan recognition, plan evaluation and error handling.

• *Expert interface concept*. The approach of Alty and Guida (1985) consists of designing an intelligent interface as an expert system that contains four sets of information: (1) knowledge of the user, (2) knowledge of the system goal, (3) knowledge of the problem domain, (4) knowledge of an intermediary module between the user (not considered here as an expert) and the system he is interrogating. From two case studies, the authors stress the difficult}' in obtaining a satisfactory man-machine dialogue when some gaps in the user model exist.

• *Hypermedia concept*. Here the operator can handle a network of concepts and ideas according to his knowledge and requirements (Nelson, 1965; Nielsen, 1990).

• *Assistant operator concept* (Boy, 1988; Valot and Deblon, 1988). In this concept, the interface is seen as an assistant to the operator. It helps to improve his ability to perform tasks. The interface must have some personal initiative, by testing some parameters or by predicting some failures for example. The operator does, however, remain the final decision maker.

• *Ecological interface concept* (Rasmussen and Vicente, 1987). According to these authors, the ecological interface design is a theory which at tempts to minimise the potential for control interference, as well as providing recovery from error. Its main goal is to design an interface that will not force cognitive control to a level higher than that required by the demands of the task, and yet provide the appropriate support for each of the three levels of activity of the human operator: skill-based, rule-based and knowledge-based (see Rasmussen, 1983).

This list is obviously not exhaustive but tries to be representative of the many original ideas that can be found. Most of these approaches are based on a user model and a task model, and in addition, a translator is often required to translate the operator's requests and commands into the systems language (Chignell and Hancock, 1988).

In continuous industrial process control, we view an 'intelligent interface' as an independent interface able to adapt itself to the operators' informational requirements using expert knowledge related to: (1) the operational context of the problem to be solved, (2) the characteristics of the users of the system, (3) the tasks they have to perform according to the general qualitative model of problem solving (Rasmussen, 1980; 1983).

In brief, our approach consists of using an expert system to ensure communication between the decision support tool, the system itself and the human operator (Tendjaoui et al., 1990). The design of an 'intelligent' interface must be consistent with ergonomic methods which will be presented in the following section.

An ergonomic approach to the design of an 'intelligent' man-machine interface

According to Chignell and Hancock (1988), designing an intelligent interface requires the use of many advanced tools and techniques. These authors underline the necessity of using task analysis techniques, expert systems and tools for interface design. They present a procedure to establish an intelligent interface whose life cycle is similar to that of expert systems or, more generally, to software products (Parsaye and Chignell, 1988). This cycle consists of several steps: task analysis, user model, conceptual design, building the task machine, prototyping the interface, evaluating the interface and redesigning.

In the field of industrial process control, we have progressively developed methods of man-machine interface design for situations where decision support tools are used to assist the operator (Millot, 1988; Taborin, 1989; Taborin and Millot, 1989; Kolski et al., 1990). This concept provides theoretical support for our current work on the 'intelligent' interface and will be described below.

The operator's ability to perform advisory tasks correctly depends on the different operating modes of the process. During a 'normal' sequence of events, the operator should be able to see the variables to be monitored. These variables (supplied by the supervisory computer) must be representative of the safe operational mode and make the occurrence of a defect obvious. Conversely, during abnormal operation, information which must be communicated to the operator comes both from the supervisory computer and from the decision support system. This information concerns, for example, alarms, diagnostic or preventative advice. The development procedure for an intelligent interface can be broken down into five sequential steps (Figure 1). The first two steps correspond to the ergonomic conceptual stage, which consists of defining the layout and content of the visual displays that will be developed. The next steps deal with the development of the interface and correspond to the ergonomic realisation and correction stages. These steps are described below.

(i) Familiarisation of the process

It is neccessary to extract data from the process model on all the technical constraints (dynamics, safety, etc.). In order to do so, well-tested methods of system analysis can be used, some of which are commonly used in automation (Millot, 1990). With this objective, Fadier (1990) distinguishes methods at design level that apply to a correctly functioning system. When defining the man-machine interface, the system requirements must be the starting point and many well known analysis tools (such as fluency graphs), allow the functional requirements of the system to take the human operator into consideration and therefore the man-machine interface to be defined. Today many of these analysis tools such as SADT, MERISE, etc, have the advantage of being available as software packages.

Other methods of analysis (i.e. when the system is not operating normally or at least with a predictable malfunction) complete our analysis, with the aim of drawing up the most exhaustive list of possible failures able to affect the system, their combinations, causes and consequences. Many of these methods are listed by Fadier (1990) and Villemeur (1988). The FMCEA (Failure Mode and Critical Effect Analysis) method, for example, is an approach which, from the cause of a failure, attempts to find the effects. The human operator is taken into account both as a means of correction and as a cause of failure. Such methods of system analysis are useful for identifying the causes of abnormal operation and determine any remedial action that has to be taken as a consequence. These actions can be the human operator's responsibility, thereby leading to a definition of the human tasks required in the man-machine system.

For such tasks it is important to be able to define the operator's informational requirements.

With this in mind, and employing a human reliability approach (Swain, 1964: Swain and Guttman, 1983), human tasks are quantified in terms of their probability of failure. They are evaluated in terms of their importance to the system in order to estimate their impact if the system should malfunction. This aspect of the study highlights the requirements of the interface. A cognitive approach based on the works of Rasmussen (1982), uses concepts based on a description of the human decision-making mechanisms brought into play in order to perform the task. It allows a more precise definition of the interface and uses 'cognitive analysis' of the tasks (Hollnaget, 1989b) indicating any informational requirements and decision-making assistance that needs to be supplied. Analysis of informational requirements allow one to choose the data that will be displayed on the control screen and to structure corresponding visual displays to assist the operator in his control of the process (De Keyser, 1988; Taborin, 1989). For example, this analysis can highlight the requirement of additional or specific displays for the detection of failures (shown in step 2 of Figure 1).

Cognitive analysis of a task depends on data related to both sensory-motor and cognitive limits in order to define the level of assistance (in decision making and/or actions). In a way, this establishes the specifications for the Artificial Intelligence (A.I.) decision-assisting systems which have to be integrated into the installation's supervisory system. Naturally, such specifications will be met according to the technical proficiency of existing A.I. systems (e.g. static A.I. systems for diagnostic support, real-time A.I. systems for supervision or exploration support). The information given by these systems must then be graphically displayed by the systems presentation mode, whose specification is dealt with in step two.

When considering the assistance system's capacity, it is advisable to define the way this system will be integrated into the supervision loop, i.e. to define the levels of automation and the manner of cooperation between the operator(s) and the 'intelligent' instrument. When this mode of cooperation has been chosen, the elements are available for making a positive specification of the Human A.I. instrument-process dialogue interfaces and/or the Human-Process interfaces (Millot et al., 1989).

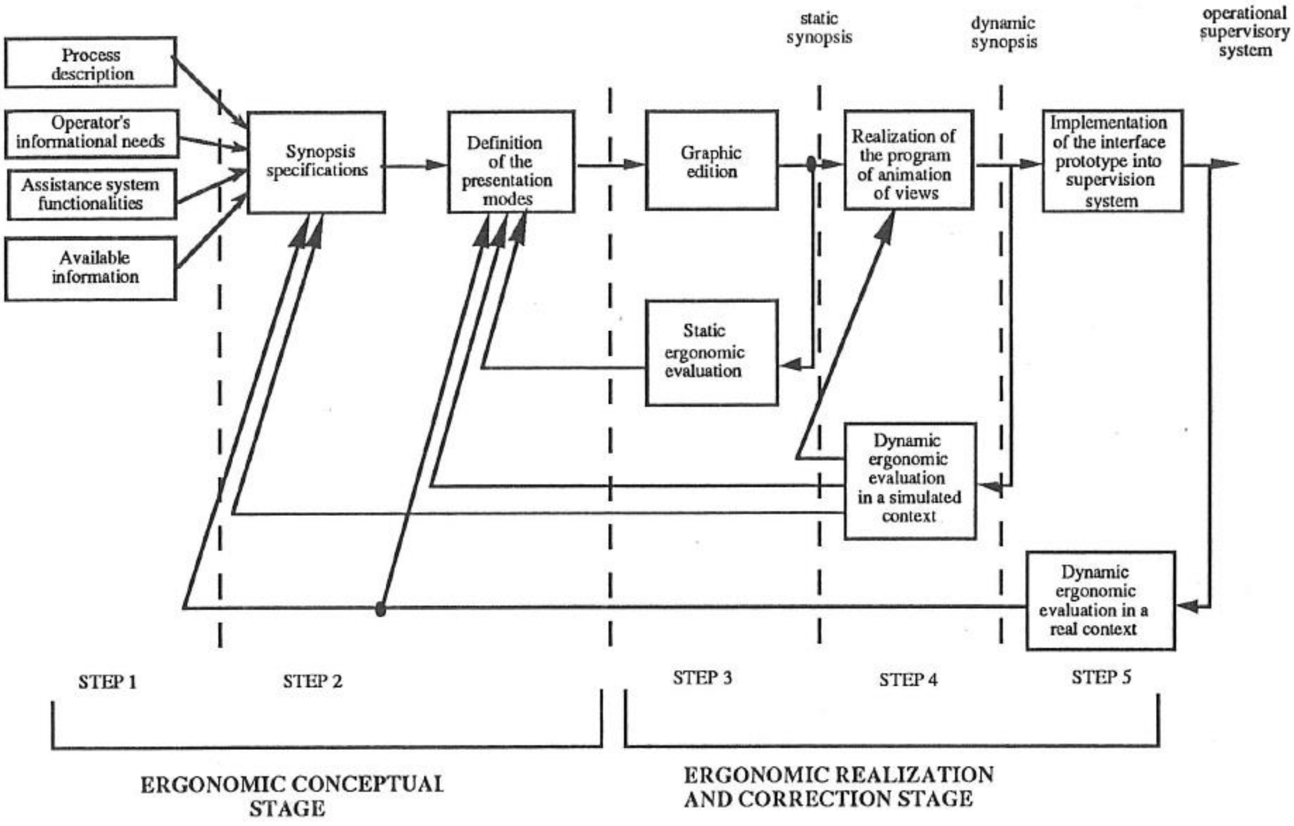


Fig. 1. The different steps used in the design of the interface between operator and decision support system.

(ii) Specifying the supervisory displays

This next step deals with the specifications of the visual displays (Figure 1). This specification must take into account the fact that the displays to be developed must handle information during normal and abnormal operation. This specification can be broken down into two parts: the first concerns the content and organisation of the displays, and the second deals with the presentation of the information.

(1) Display content

The designers of the decision support system must describe its different functions and establish the amount of information that can be derived from it. For example, a diagnostic function can conclude several fault hypotheses from amongst a pre-defined set, and for each of them calculate a credibility factor. This second step then, consists of identifying that information which is relevant to the operator's needs and in specifying the way in which it will be presented to him.

Finally, this second step specifies the organisation of the displays ensuring that only information that is useful to the operator will be presented (see Lind, 1982 or Praetorius and Duncan, 1989). This phase is crucial because this organisation determines the cooperation between the decision support system and the human operator. Solving the potential conflicts that can occur between the operator and the decision support system (when the operator does not agree with its advice for example), depends on this cooperation. In such cases, the system must lead the operator through the conclusions corresponding to the different steps of his reasoning process in order to find the origin of the conflict. For this purpose, the solution consists of a parallel analysis of the problem solving process of the human and the system in order to provide the operator with justifiable and relevant information to facilitate an agreement as quickly as possible (Taborin and Millot, 1989).

The designers, after organisation of the displays has been completed, must then define the way in which this information is to be presented. Such a choice depends directly on the classification of supervisory and control tasks to be performed. For example, the operator will need specific displays when the process operating status is normal and specific displays allowing him to evaluate, diagnose and correct the process during abnormal operation.

(2) Presentation

When specifying the presentation of information on the displays, several ergonomic considerations must be taken into account. For instance:

- the organisation of a structured multi-window display. Such a structure is similar for all types of display and each window is dedicated to a particular scenario allowing the operators to develop very efficient responses;

- to ensure consistency between the chosen presentation modes and those already in use in the control room;

- the choice of symbolic presentation in order to facilitate rapid, clear interpretation of the information.

During this phase it is important to let the operators state their preferences towards different presentation systems (Gould and Lewis, 1985; Scapin et al., 1988). In fact their experiences can positively influence the final result and promote their acceptance of the system in the control room.

(iii) Graphical editing and static evaluation of the displays

Once the characteristics of the displays have been defined, the third step is concerned with actually drawing the displays - generally by means of graphic editors. Editing displays leads to a primary set of displays called 'synopsis'. Their ergonomic qualities must be evaluated in order to improve their legibility and it is therefore neccessary to apply ergonomic criteria with respect to human information aquisition capacities, for example:

- the choice of graphical presentation to suit the information to be presented, i.e. bargraph vs. curve, analogue display vs. digital display, etc.

- the choice of shape of the different symbols used for displaying process components in order to enhance the operator's perception of the process;

- appropriate sizes, colours and contrast levels; - the arrangement and layout of the displays;

- the amount of information that can be displayed simultaneously.

The ergonomic criteria applied are governed by the rules of design. However, there are many general rules to be observed, some of which are specific to a particular industry. This is the case in the nuclear industry where specific standards must be applied. At present, current research tends to define methods or create tools with a view to promoting such considerations in the design of 'synopsis'. One such development, the GRADIENT project (part of the ESPRIT program), is devoted to the development of expert systems for supporting control room operators and graphic systems in the fields of process supervision and control (Elzer et al., 1988; Johannsen et al., 1986). We can also cite the SYNOP expert system which is used for the static evaluation and automatic improvement of control displays (Kolski, 1989; Kolski et al., 1988), and other studies related to the ERGO-CONCEPTOR system composed by a set of interactive graphical design tools, based on the informational requirements of the operator (Moussa et al., 1990).

In order to improve perception and interpretation of information, more research of this t)pe is needed to study and evaluate new graphical presentation modes. For example, Beringer (1987) proposes variants of the 'star' display, whose principle is defined by Coekin (1968); Brown (1985) compares many graphical representations of data processing tasks; Elzer et al. (1988) study new presentation modes in the process control fields; Lind (1982) introduces functional method to process behavior that echoes many current industrial applications, and Siebert et al. (1988) compare the operators performance using three types of interface in a simulated accident scenario in a nuclear reactor.

(iv) A prototype of the interface

A prototype of the interface must be built in order to assist in the development of the programming of the displays. This program is based on a model of the man-machine interactions previously studied with reference to the different process operations. Such an evaluation requires a process operation simulation which can require a significant effort but leads to the construction of an interface that will be close to the final one. It reduces the work involved in integrating the interface into the real supervisory system on-site which would otherwise require interruption or complete closing down of the process.

(v) Implementation of the interface and ergonomic evaluation

This fifth step is concerned with on-line implementation and evaluation in real life conditions. The importance of such a stage can be reduced if step four has led to a useful prototype.

This evaluation is aimed at enhancing the content (especially the lack of it) of displays, and at verifying its concurrence with the operator's cognitive activities. Several complementary methods exist to carry out this evaluation, e.g., cognitive task analysis methods (Woods et al., 1981), and subjective methods (such as questionnaires) which consist of asking the operators questions about differing characteristics of the interface and are aimed at emphasising difficulties that may eventually be met during the execution of its tasks (Gertman et al., 1982). Many other approaches are applicable, for instance those led by Boy and others (1988), using audio-visual means, and De Keyser et al. (1987), who studied the method and frequency of using the information support given to the operator. Many other approaches exist in literature on the subject of ergonomics; Sperandio (1988), Wilson and Corlett (1988) and Abed (1990). Their methods can be complemented by more quantitative ones that concern in particular the measurement of the operator's workload or performance in order to identify those tasks that induce a high workload and which therefore justify an improvement of the interface (Millot, 1988). The choice of a particular method depends on the application and most especially on the use of any dedicated sensors in the control room. This last step will provide a working interface, or one which requires further development over previous steps (Figure 1).

Our work concerns us with the application of displays utilising 'intelligent' image management. The term 'intelligent' in this context reflects the capacity of the image system's ability to adapt content and presentation to the operator's needs during different operational processes. This approach will be described in the following section.

'Intelligent' interface: The D.M.I.

Our approach is tailored to the field of process control and our goal is to design an intelligent image manager which we call the 'Decision Module of Imagery' (D.M.I.). This approach can be integrated into a global model of the man-machine system in the control room to obtain a general assistance tool (Figure 2).

The supervisory computer centralises process data which is accessed both by the decision support expert system and the D.M.I. This data is used by the decision support expert system to derive information such as predictive, diagnostic or recovery procedures. This information is transferred to the D.M.I., which selects information that can be presented to the operator. This selection process is based on a task model to be performed by the operator, and an 'operator model' containing information on the operator.

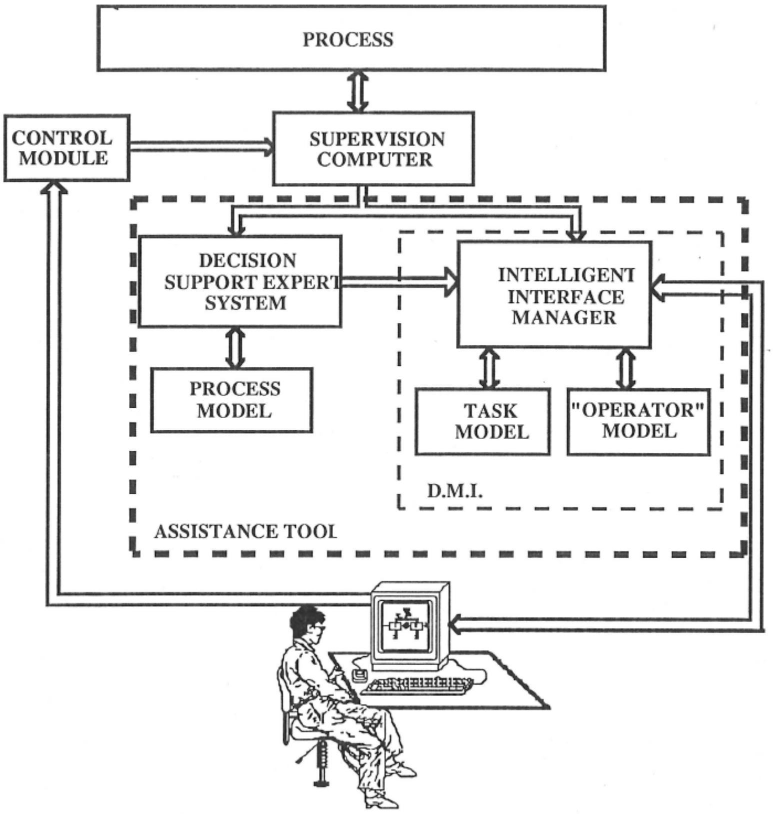


Fig. 2. Global Man-Machine system using the concept of intelligent interface

The task model is currently restricted to problem-solving tasks and is derived from analysis of the fixed tasks to be performed by the operator. This model is based on the general qualitative model of Rasmussen (1980) whereby a task is analysed through four information processing steps: event detection, situation assessment, decision making and action. This task model contains process significant variables used by the operator whilst performing his different tasks.

The operator model integrates ergonomic data which is presently restricted to:

- three possible levels of human expertise e.g., unskilled, experienced or expert. It is then possible to: (1) adjust the displayed level of detailed information, and (2) regulate the degree of control granted to the operator based on his level of expertise.

- the type of displays associated with the operator's cognitive behavior according to Rasmussen's model.

- the presentation mode associated with each type of display e.g., a 'reflex display' is one which offers advice through text designed to assist the operator through his decision-making processes.

The aims of the D.M.I. are:

(1) To select data that can be displayed on the screen taking the operational context of the process and the informational requirements of the operator into account, in order to enable him to supervise the process and define possible corrective actions in the event of failure;

(2) To define the ergonomic parameters associated with the presentation of information in order to assist the operator's conception;

(3) To add corrective advice, provided by the decision support expert system, to the display in order to justify its reasoning and thus to prevent possible conflicts between itself and the human operator (Taborin and Millot, 1989).

To meet these goals, the D.M.I. has to be autonomous and able to adapt itself to the operator's needs. The D.M.I. must therefore be able to integrate expert knowledge on:

(1) the different operational contexts of the system, to be supervised;

(2) the characteristics of the different users of the system;

(3) the cognitive and manipulative tasks that these operators have to perform.

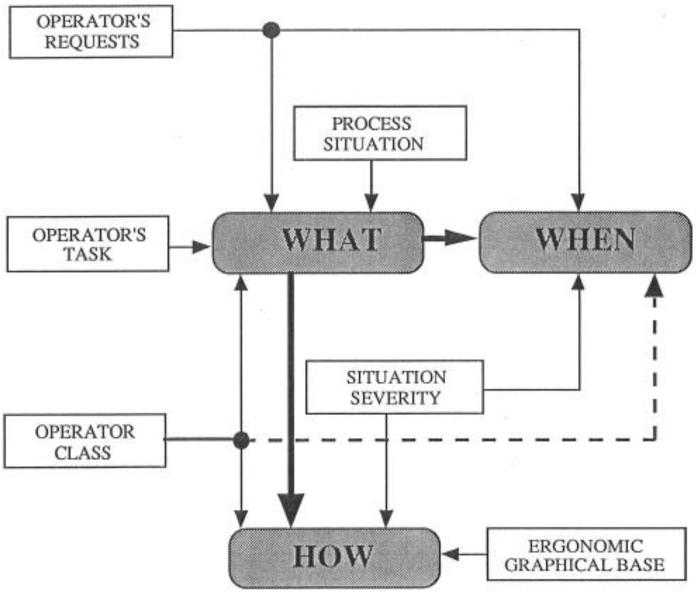


Fig 3. The "What / When / How" notion

Such information allows us to answer questions related to ergonomic considerations (Figure 3):

(1) What to present to the operator (we consider here the 'what' contains the 'why', by using justification scales of the information displayed):

(2) When shall we display it;

(3) How shall we display it.

These three issues present problems which are discussed below.

The ' WHAT' problem

The problem concerning what is to be displayed to the operator depends essentially on three things:

(1) Operator requests: if the operator, when performing his supervisory tasks, requests information, i.e. a variable state or justification of an action, then the D.M.I. has to meet this request.

(2) Operator classification: if the decision support tools perceive an error in the system and propose advice or action, the operator can (i) be in agreement with this advice and act accordin~y or,

(ii) disagree and request some justification for the advice. The level of detail in this justification will depend on the operator's skill level, e.g., a novice operator will tend to require more detailed justification than an experienced operator.

(3) The operator's task in relation to the different process operations: the operator's tasks and therefore his informational needs will change according to the state of the process (Rasmussen, 1986; Rouse, 1983). Figure 4 shows the different cases where the D.M.I. can

intervene and different messages or displays that can be selected by the operator with respect to the different states of the process. For example, in a transition situation, the operator may need some advice on starting the process, whereas to assess the effects of a corrective action, the operator needs information about the progression of the correction. During an abnormal process state, alarms are automatically selected and displayed, but where an 'uncommon' abnormal situation develops, the D.M.I. can focus on variables that can affect the system's production and/or security by suppressing all information or alarms that do not affect either production or safety.

The 'WHEN' problem

The problem concerning 'when' relevant information has to be presented to the operator de pends on the nature of the information that he requested and also on the seriousness of any impending situation. Severity evaluation is bound by losing production and security constraints. To know when the D.M.I. has to display information, we first have to know what this information actually represents (the 'WHAT').

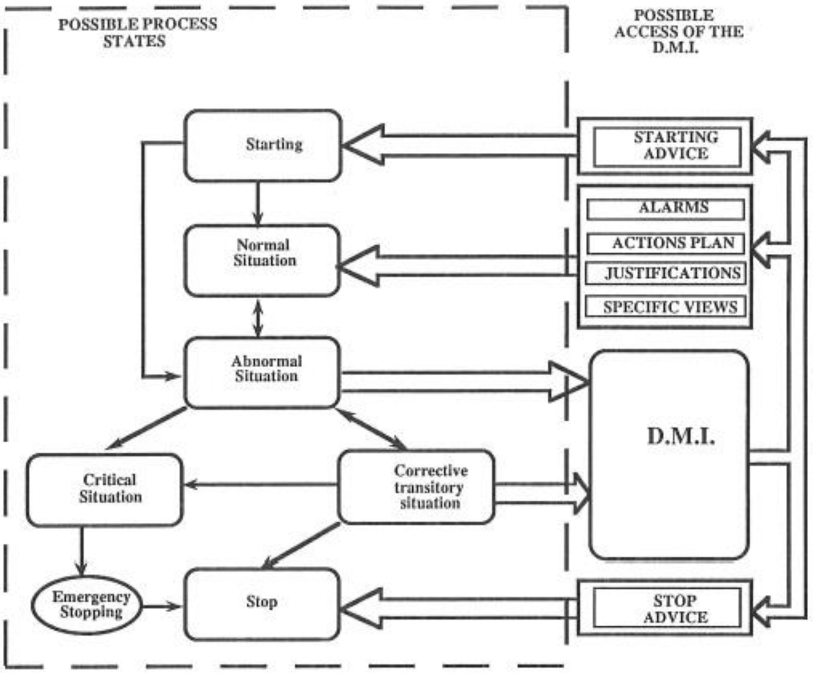


Fig. 4. An example of assistance available to the operator during different process states.

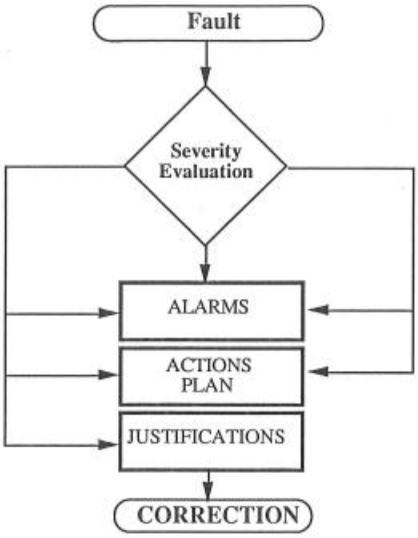


Fig. 5. Example of messages management in relation to the severity of process situation

For example, alarms are displayed to the operator as soon as they occur, whereas information on action or advice proposed by the decision support tools is only displayed to the operator when requested or when a process situation becomes hazardous (Figure 5).

The D.M.I. has, however, to evaluate the mental workload of the operator in order to determine whether any additional information could be adequately assimilated by him. Mental workload depends on many factors, e.g., the number of potential hazard situations encountered, their severity, the operator's skill level, etc.

The 'HOW' problem

To know how to present a piece of information to the operator, we first have to know what this information represents and the severity of the process fault at that moment. Information is then displayed in accordance with predefined ergonomic modes (Figure 3). If several different presentation modes are available to the operator which can be used with the same efficiency, then he can configure the interface according to personal preference. Some examples of 'HOW' are:

- To indicate the progression of a variable during the process, graphical curves might be appropriate. They inform the operator about trends in the variables history.

- The colour red for example, can be used to indicate a state of danger in the process.

The integration of the D.M.I. in a supervisory system, and its software architecture, are described in the following section.

Implementation of the D.M.I. in an experimental supervision system

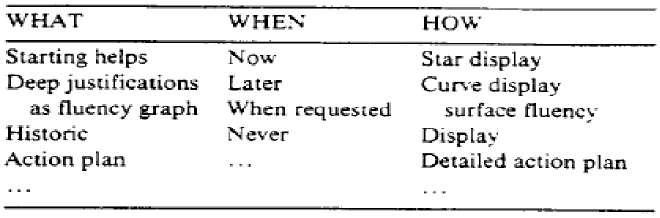
This experimental platform integrates the D.M.I. into a supervisory experimental process written in the 'C' language and is based on a VS/3100 station. Graphics are created with the graphical tool DATAVIEWS.

Software architecture

The software architecture is shown in Figure 6. Information deduced by different modules is shared in a memory whose access is coordinated by a supervisor. Memory is shared between the following modules:

- An inference module which takes facts from the shared memory into account and uses rules from the knowledge database. These rules are issued (i) from the operator's prescribed task analysis, (ii) from the answers to the 'What', 'When', 'How' questions, and (iii) from an ergonomical graphics database. Their conclusion may have different values. Examples of possible values are given in table 1. Two simple examples of rule representation are given below (for more details please see Tendjaoui et al., 1991).

Table 1. Example of possible values associated with the concepts ‘WHAT’, ‘WHEN’ and ‘HOW’.



WHAT	WHEN	HOW
Starting helps	Now	Star display
Deep justifications as fluency graph	Later When requested	Curve display surface fluency
Historic	Never	Display
Action plan	...	Detailed action plan
...		...

WHAT
RULE NO. 56
IF FUNCTIONING SITUATION = ABNORMAL
AND OPERATOR CLASS ---- EXPERIENCED
AND REQUEST = NO REQUEST
AND OPERATOR TASK = PROBLEM SOLVING
THEN WHAT = ACTION PLAN

WHEN
RULE NO. 25
IF WHAT = SURFACE JUSTIFICATION AS
FLUENCY GRAPH
AND OPERATOR CLASS = NOVICE
AND SEVERITY = 8
THEN WHEN = NOW

- An operator database is used by both the supervisor and the inference module so that the operator's individual needs may be realised whenever possible.

- A scenario management module which simulates the decision support tool (see Figure 2). It can reason information on alarms, action plans, etc.

- A module which manages the operator's actions and requests usually saving them into files for later use. This module is connected via an interpreter.

- A graphics module able to animate and manipulate the displays.

- A module which simulates the process to be controlled and supervised. It reads commands from, and writes its results into the shared memory. This module is connected to a prediction module able to provide impending information on system variables.

The simulated process

This simulated process represents a simplified power plant and is shown in Figure 7. We have considered 16 variables, arranged in five classifications and these are shown in table 2.

The method of simulation used consists of creating a propagation network, where a node represents a variable and a link represents the propagation effect between variables. A link is represented by four parameters which are: (i) the gain, (ii) the response time, (iii) the delay and, (iv) the influence (+ or -). More details on these modelling principles can be found in Caloud, (1988) and Feray-Beaumont, (1989).

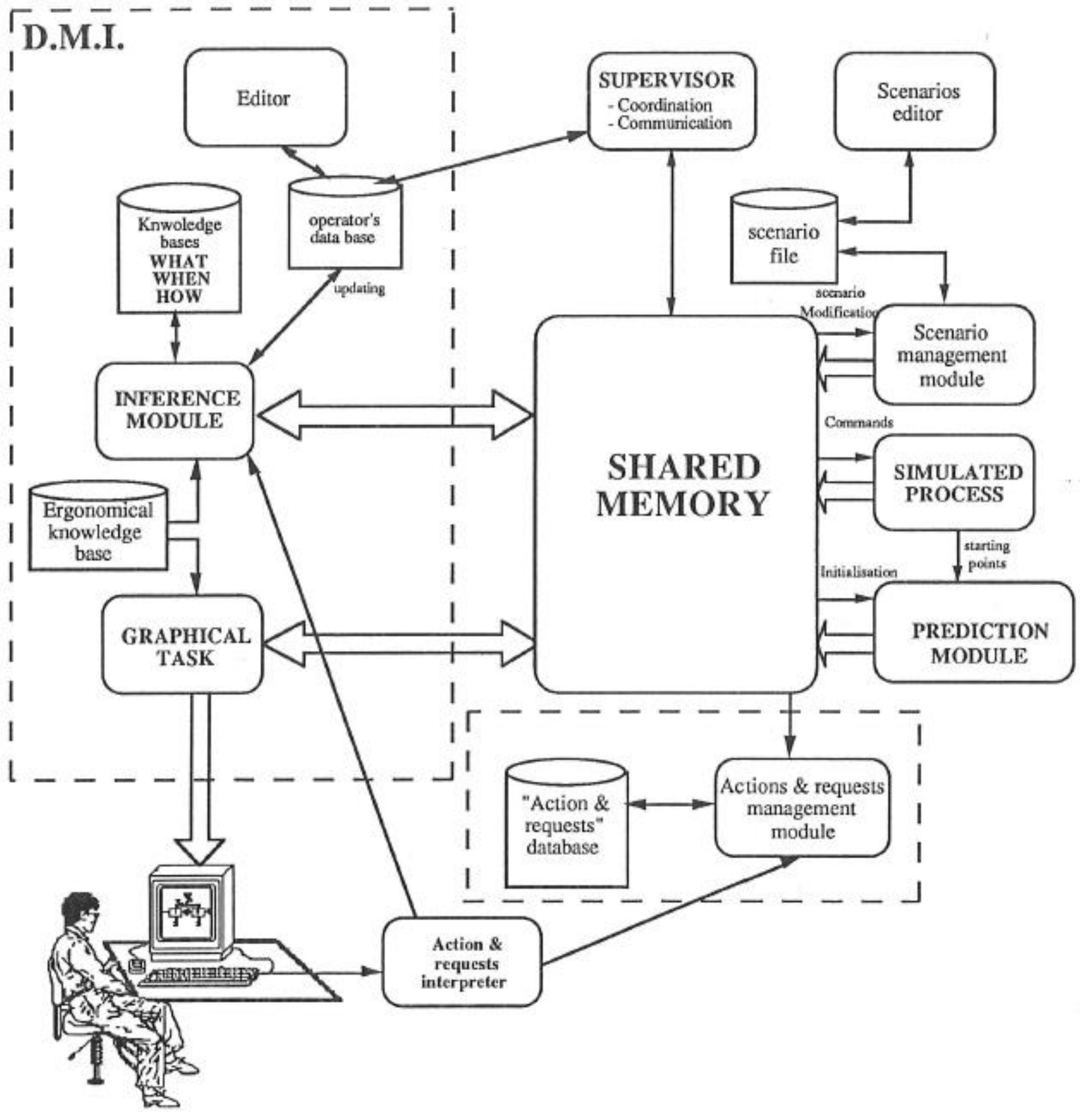
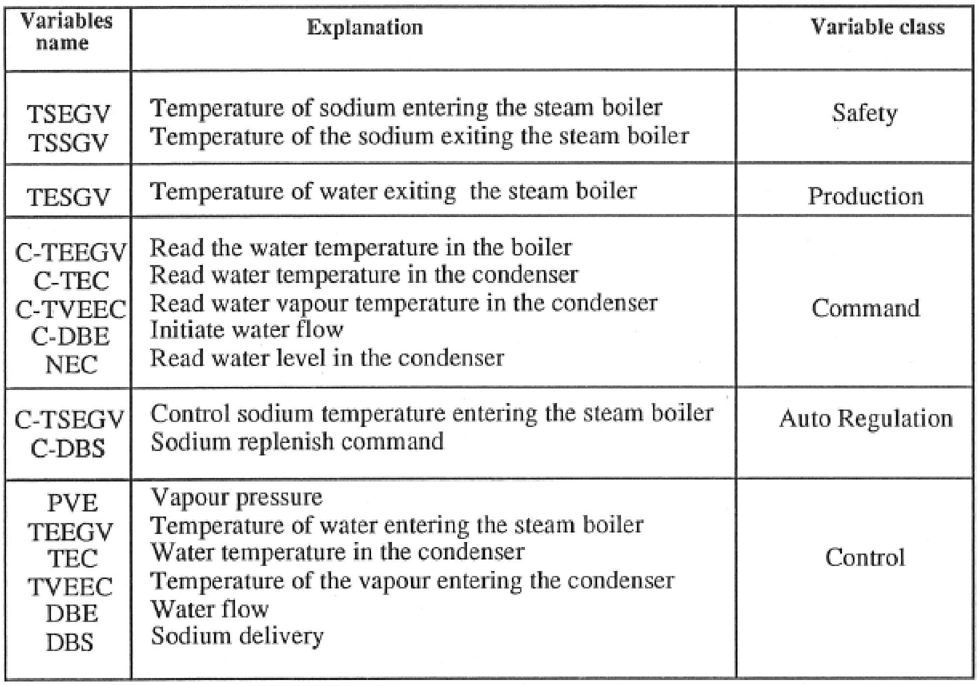


Fig. 6. Experimental platform architecture

Table 2. Legend of process variables used in our power plant simulation.



Variables name	Explanation	Variable class
TSEGV	Temperature of sodium entering the steam boiler	Safety
TSSGV	Temperature of the sodium exiting the steam boiler	
TESGV	Temperature of water exiting the steam boiler	Production
C-TEEGV	Read the water temperature in the boiler	Command
C-TEC	Read water temperature in the condenser	
C-TVEEC	Read water vapour temperature in the condenser	
C-DBE	Initiate water flow	
NEC	Read water level in the condenser	
C-TSEGV	Control sodium temperature entering the steam boiler	Auto Regulation
C-DBS	Sodium replenish command	
PVE	Vapour pressure	Control
TEEGV	Temperature of water entering the steam boiler	
TEC	Water temperature in the condenser	
TVEEC	Temperature of the vapour entering the condenser	
DBE	Water flow	
DBS	Sodium delivery	

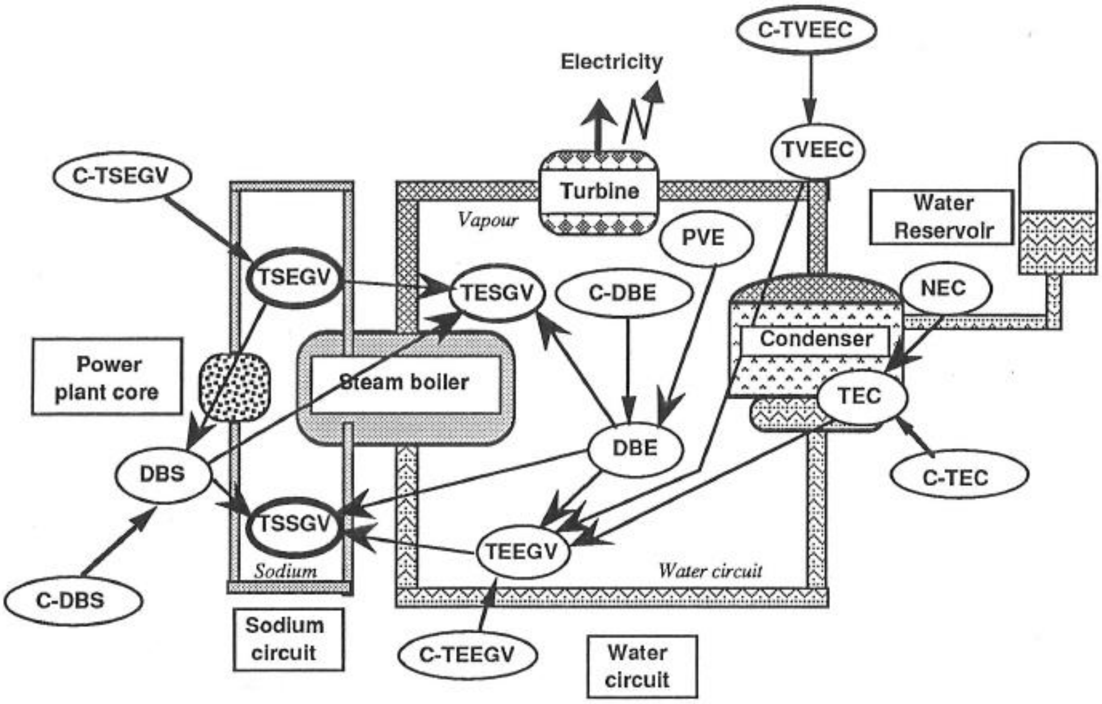


Fig. 7. Location and influence of the variables in the simulated process

The operator's prescribed tasks

The operator's principal objective is to optimise system production without compromising safety. To do this the operator utilises the command variables shown in table 2. In order to assist the operator, graphical displays are managed by the D.M.I. Each display is divided into 5 zones (Figure 8). Zone A is used to display alarm and action advice, zone B is used to display text providing justification of actions. Zone C - the most important - contains graphical information and zone D is used for dialogue with the D.M.I. Zone E is used for process dialogue. Figure 9 shows an example of a display giving information on the history of a variable.

Figure 10 shows operator activity when faced with different process states. After having started the system, the operator has to bring production to a predefined output level without compromising safety. As soon as a malfunction is detected or predicted by the decision support tool, an alarm is displayed in zone A of the screen. The operator is then confronted with cognitive tasks (which can be represented by the general model of Rasmussen 1980; 1983).

The operator is presented with a plan of action at this step, by which if the plan is correct, the situation is brought under control, otherwise such a situation will become abnormal again or can, in some cases, become critical. Under critical conditions, emergency shut down procedures are instigated. At this stage, the 'What', 'When' and 'How' rules that allow the D.M.I. to assist the operator (Figure 10), are being implemented by the knowledge database of the system.

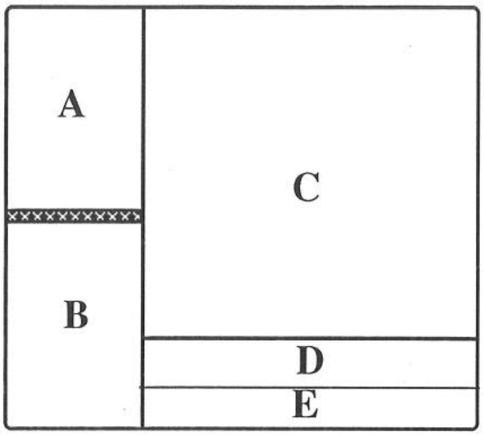
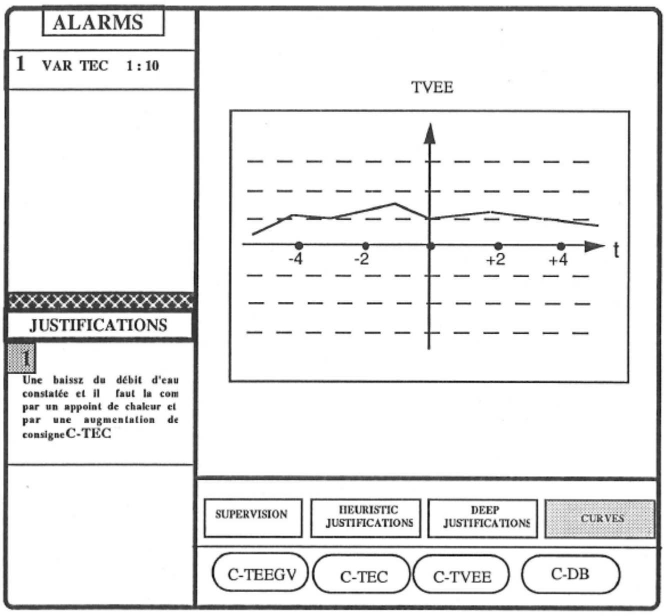


Fig 8. The 5-zone composition of a display



Une baissz du débit d'eau constatée et il faut la com par un appoint de chaleur et par une augmentation de consigne C-TEC

Fig 9. Display example: Variable history

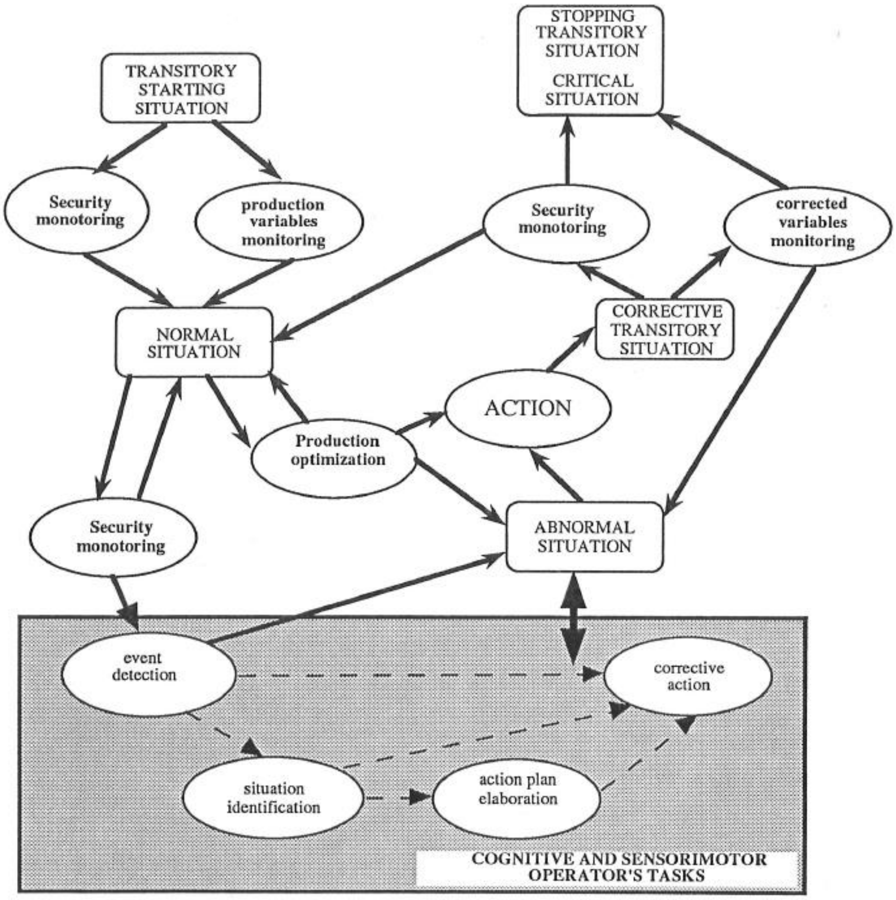


Fig. 10. Operator tasks analysis according to different operating situations of the process

Discussion

In order to optimise man-machine communication, we used Artifical Intelligence techniques and it seems that Artificial Intelligence can contribute solutions to some of the problems encountered in the field of process control/man-machine interaction (Elzer and Johannsen, 1988; Millot, 1990). The first version of the D.M.I. contains approximately 80 rules in the 'WHAT' database, 70 rules in the 'WHEN' database, and 110 rules in the 'HOW' database. These rules are compiled in such a way as to be easily exploited by the inference module that controls the graphics display (for more details see Tendjaoui et al., 1991).

At present the D.M.I. attempts to fulfil the following objectives:

- Adapt itself to the operator: This problem is solved in three steps. Firstly, the D.M.I. uses rules from the 'WHAT' database in order to decide which information is to be presented to the operator. Secondly, armed with data on the severity of the problem and the skill level of the operator, the D.M.I. uses rules from the 'WHEN' database to decide at which moment this information is to be presented. This temporal control over the display allows the D.M.I. to adapt itself to the different operational situations of the process. Finally, using data known about ergonomic and operator preferences, the D.M.I. uses rules from the 'HOW' database to decide on the form of data presentation.

- Helping the reasoning of the operator: the D.M.I. identifies the operator's task using information on the severity of the problem and the status of the process, and guides him with useful information.

The D.M.I.'s capacity to adapt and reason has an impact on:

- The operator's learning curve: the flow of information and its level of detail are managed by the D.M.I. according to the experience level of the operator. The D.M.I. can be used as a formative tool and, in a working situation, its characteristics can improve the operator's experience.

- The operator's workload: The operator's workload will decrease because the D.M.I. displays only information to the operator that is useful and in a form that he can readily understand.

These points will be analysed and evaluated at a later date and will almost certainly highlight some shortcomings of the D.M.I., but it is possible to list below some problems that are the object of our current research and that have allowed us to arrive at an evolved system.

- Consideration of the experience that the operator has of all the different sub-processes. He may, for example, be considered an expert in one sub-process and a novice at another. This experience level depends particularly on operator performance, operator error and on unknown situations that the operator may have already solved.

- Optimising the adaptation between the state of the process and the mental image of it that the operator has, using the D.M.I.

- Integrating a human operator model into the D.M.I. in order to identify, in real time, his cognitive task and to provide appropriate support to his decision.

- Dynamic evaluation of the operator's mental workload.

- Keeping records of uncommon situations and making them available to the operator via the D.M.I. when neccessary.

Conclusion

The advent of new techniques in the fields of Artificial Intelligence, graphical interface design and operator task analysis are at the moment contributing to vast improvements of man-machine interfaces in industrial control rooms.

In this paper, we have tried to provide a method of man-machine interface design consisting of five steps (figure 1). The first two steps correspond to the ergonomical conceptual stage and consist of defining the layout and the content of displays. The remaining steps deal with the development of the interface and correspond to the ergonomic realisation and correction stages.

With the 'intelligent ' display management as our goal, we have used these five steps to develop our D.M.I. (Decisional Module of Imagery) concept. This stage is soon to be completed and we are currently working to bring the D.M.I. to the stage where its ergonomic qualities can be evaluated. When implemented, this stage will be based on an experimental platform simulating a nuclear power station - some of this work will be carried out in the laboratory - the results of which will be published in a future paper.

Acknowledgement

The authors would like to thank an unknown reviewer for his or her helpful comments, and Martin O'Neill for his Anglicisation of this manuscript.

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