

INTERFACE DESIGN IN THE PROCESS INDUSTRIES

M. C. Beaverstock
The Foxboro Company
Foxboro, Massachusetts
R. G. Stassen
Delft University of Technology
Delft, The Netherlands
E. A. Williamson
The Foxboro Company
Foxboro, Massachusetts

I INTRODUCTION

The application of control and information processing systems involving complex man-machine systems is still expanding as a result of ever increasing levels of automation. As a consequence, a stage of automation has been reached in which a number of the human operator's mental processes are being taken over or augmented by such systems, resulting in modifications of the human operator's task. Criteria and guidelines for allocation of system functions between man and machine should therefore be established, but a general methodology is presently not available.

The supervisory control situation can be explained best by the block diagram of Figure 1. A plant is automatically controlled by a set of controllers; the

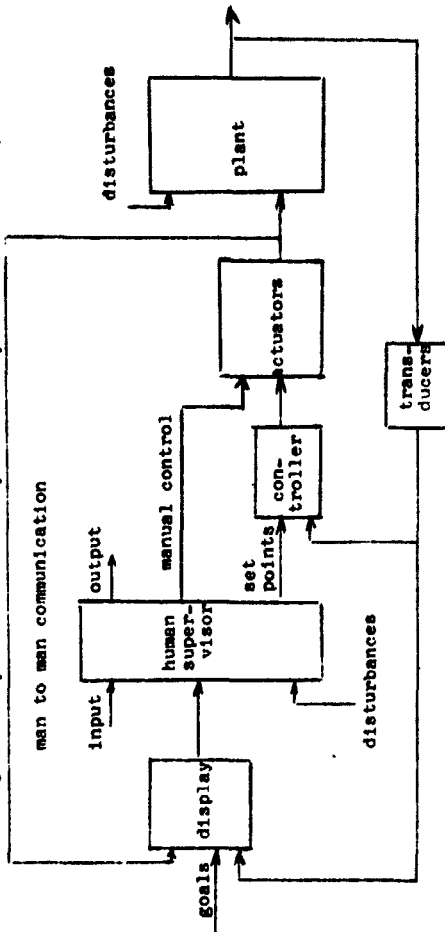


FIGURE 1: SUPERVISORY CONTROL SYSTEM

Presently he is on sabbatical leave at MIT, Cambridge, Mass. for the academic year 1976-1977.

Presently with Metromation, Inc., Princeton, N.J.

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Every operator runs his plant in accord with his own mental model of the process. In this sense, one characteristic of an ideal man-machine interface is that it be in harmony with that model.

With this theme in mind, the paper first reviews the functions of the process operator and compares them with human operators involved in control situations previously studied outside of the industrial environment (pilots, air traffic controllers, ballroom, etc.). A brief history of the operator interface in the process industry and the traditional methodology employed in its design is then presented. Finally, a much more fundamental approach utilizing a model definition of the human operator's behavior is presented.

This entire topic is important to the fluid process industries. Indeed, it may be stated that: "He who specifies the process control system (and the accompanying displays) specifies the plant operating procedures - and, hence, the operating economics."

- outputs of the transducers are compared with setpoints and revise controller outputs to the final actuators. The human supervisor is informed about the plant conditions via a display system; he monitors the system, he generates setpoints, he makes decisions whether he should intervene or not, he plans control strategies, and he communicates with other human supervisors. The task of the human supervisors can be summarized as follows (Figure 2):
- Learning, understanding, and interpreting goals required of him (actually constructing).
- Monitoring the system outputs so that from the control actions, he can identify the dynamics of the system and the noises acting on the process.
- Planning and determining which control actions should be performed.
- Inputting the appropriate data to the control system for both initialization and on-line adjustments.
- Intervening in order to switch from manual to supervisory control.

The tasks mentioned above deal with three categories of system functions (Rajnsdorf, Rouse, 1977):

- Supervision and control of process operation.
- Coping with malfunctions.
- System evaluation and improvement.

The human operator has been studied in terms of his tasks and function in many situations (pilot, air traffic control, etc.) other than an industrial environment. In the fluid process industries (chemical, petrol, textiles, food and drugs, metals, pulp and paper), the human supervisor's behavior (and his task) is quite different from that in the many reported studies in vehicle control.

Four different aspects of human supervisor data processing can be recognized with regards to the information to be handled:

- INFORMATION: what type of information should be presented and how much of it?
- PRESENTATION: how should the information be presented?
- MANIPULATION: how should the information be manipulated by the operator?
- CONFIGURATION: how should the presentation and manipulation characteristics be physically arranged to form a work station for the human operator?

With reference to these four aspects we can distinguish the differences between vehicle control and process control; these differences are listed in Table 1. In addition to this table we should add one other important fact. Usually a plant is designed initially from a process point of view, then controls are considered, and finally the human tasks are determined; an integrated design of the machine function is seldom employed.

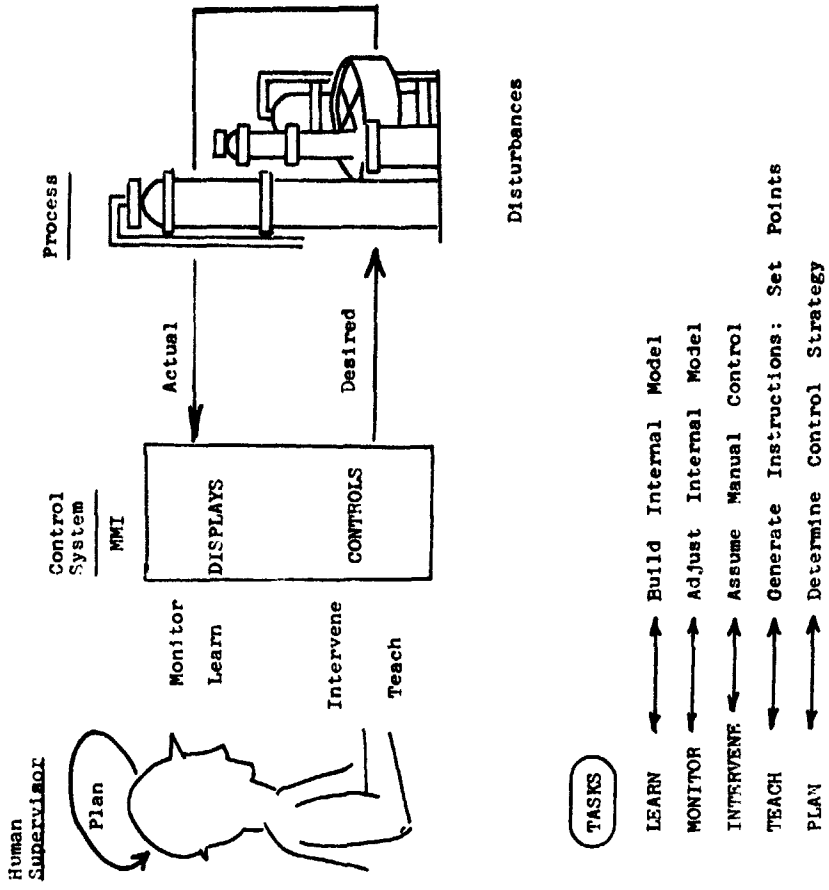


FIGURE 2: THE TASK OF THE HUMAN SUPERVISOR

However, displays for these operators in the fluid process industries as well as the automatic control systems, play a very critical role in the operation of a whole plant. Indeed, it may be stated that: "He who specified the process control system (and the accompanying displays) specifies the plant operating procedures - and hence the operating economics." This means that the designer also determines the task of the supervisor and really allocates the system functions between man and machine. Therefore the designer should not only be knowledgeable about the control possibilities and process dynamics of the plant, but he also should be able to take into account human capabilities.

Even with such incentive, little has been done to systematically study the way an operator carries out his assigned task to operate a plant and then make that knowledge available to a designer to define the appropriate display. To understand this solution requires a realization of the interfaces between man and the plant he controls as it exists in the process industries. Over the years, while plant operating practices have hardly changed, the interface has gone through significant changes so that before thinking about the future it is worthwhile to consider the past.

BRIEF HISTORY OF THE HUMAN OPERATOR'S FUNCTION

Looking back one sees that the operator/process system was tightly coupled. "Measurement" and control devices were located next to, or on, the associated equipment. The tools an operator worked with for viewing and manipulation were such things as gauges, handwheels, levers and sight glasses. The operator was "in touch" with his environment as shown in Figure 3. The operator himself determined the operating procedure. His "experience" was a key to the successful operation of the plant. He constantly came into physical contact with the process. His sense of smell could detect overcharging of an ingredient or an incomplete reaction; by sight and touch he could tell the quality of the material he produced; and a slight vibration could warn him of an imminent pump failure. However, the process equipment tended to be widely separated and, therefore, much manpower was required and expended, and control in general was much less than perfect.

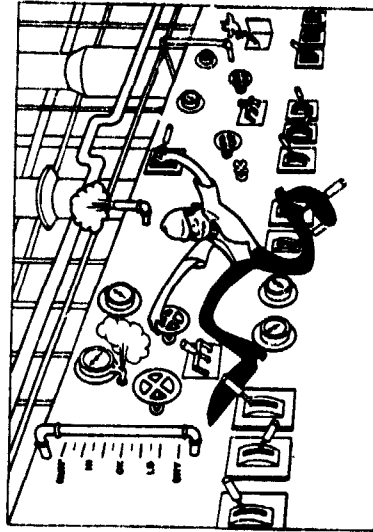


FIGURE 3 - Operator "In Touch" With The Process

Data Processing Aspects	Vehicle Control	Process Control
INFORMATION		
Type	Direct	Indicative
Dimension	About 10	Between 100 and 1500
Time constants	From sec. to min.	From min. to hours
Abstractness	Low	High
Origin disturbances	Known	Unknown
System properties	Linear	Non-linear
	Constant	Time-varying
PRESENTATION		
Integration	Integrated displays	Non-integrated displays
Parallel/series	Mostly parallel	Parallel and/or series
Number of displays	Low	High
Time window	Instantaneous and predictive	Instantaneous and history (trend)
Modes	Visual, seditive, vestibular	Visual, seditive
Overview	Good	Poor
MANIPULATION		
Direct feedback	Proprioceptive	No proprioceptive
Response	Immediate	Next shift
Strategies	Error correction	Boundary control
Accuracy	More or less consistent	Variable
	Quantitative	More or less qualitative
CONFIGURATION		
Physical size	Small	Large
Personnel training	Highly and consistently	Less rigorously
Human factors	Well developed	Very little developed

TABLE 1: COMPARISON BETWEEN VEHICLE CONTROL AND PROCESS CONTROL

As the size and complexity of processes increased, more efficient methods for monitoring and control were required. This need led to increasing degrees of centralization made possible by developments in measurement, transmission and automatic control. Much less manpower was now required and the operator's role changed to require him to give more attention to supervising the process rather than taking part in the details.

Increasing degrees of centralization introduced more changes. The operator now had more data than he could use effectively. He was also physically separated from the process since most control equipment was placed in a control room. Early control rooms still retained a window to the process unit but even this disappeared with new safety requirements. Consequently, the operator's "touch" with the process was lost. There now developed the man-machine allocation problem. Another important change also occurred. The operator lost his ability to define his own operating procedures. These procedures were now dictated by the control system and display design, and thus by the designer of the system. Tradition in design replaced the operational alternatives previously exercised by the operator.

The traditional operator/process interface today is the panel. It contains the measurement and control information that the operator is assumed to need to carry out his assigned tasks. Because an operator is expected to control a number of plant sections, he must visualize the control panel as a hierarchical display which shows him an overview of the operation as well as allow him to change individual controllers. This hierarchy is shown in Figure 4.

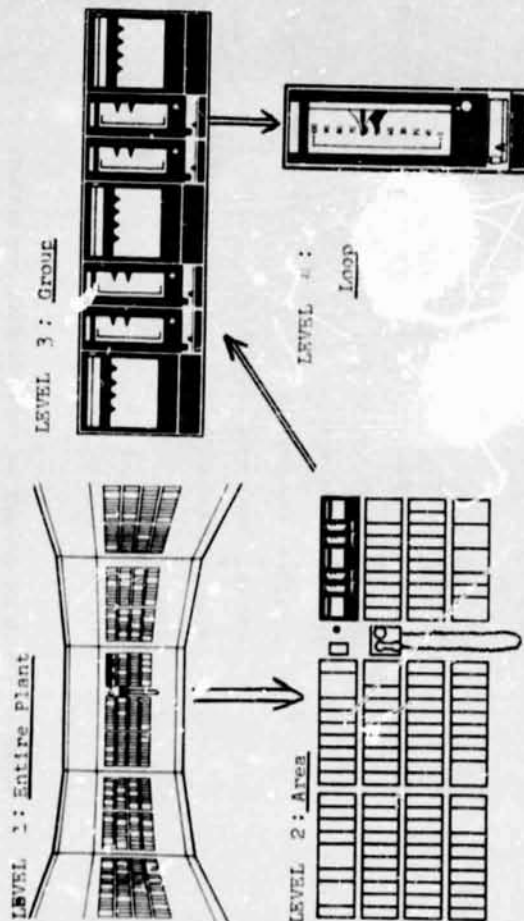


FIGURE 4: CONVENTIONAL PANEL HIERARCHY

Other characteristics of the traditional panel are (Kitchenka, Williamson, 1977):

- **Size:** Most often the size of a control room is predicated on the size of the panel it must contain. The panel's size is directly proportional to the number of loops it must handle. Considering modern construction standards and expense, many dollars could be saved by reducing the size of this structure.
- **Inflexible Layout:** Since the panel is usually constructed of steel and each display is wired to suit a particular process control function, changing process control system requirements usually does not result in corresponding changes in display layout.
- **Functional Separation:** A typical panel is designed with alarm annunciation across the top, analog-type process indication and recording on its vertical midsection, and on-off (motor and electrical) functions on the lower portion. The operator is required to re-associate all of the process-related but physically separated functions necessary to isolate trouble and effectively supervise the process control system.
- **Parallel Information Display:** The components of a panel present all of the information that they are designed to present all of the time with no potential for selectivity. The operator must, therefore, assimilate this enormous mass of information and attempt to visually and mentally cull out that which is pertinent to any particular situation.

It is important to note that the panel design and display format are usually developed based on the designer's "experience" in understanding the role of the operator and his needs. Infrequently some degree of human factor may be added when the selection of colors or positioning of pushbuttons is involved. In general, the operator display and, at times, the entire control system is almost included as an afterthought to the design of the plant. At times the control system design is even carried out after the process design is fixed (Figure 5) by engineers or contractors who do not have responsibility for the operation of the plant. Consequently, this usually means a study of human operator behavior and a definition of his task was never included in the early planning of the installation. At this late stage, it is economically infeasible to change the process design and, therefore, there is a great tendency to "live with" the control design rather than make changes to the plant design. Consequently, discrepancies between the operational aspects of the control system and the original process objectives can occur. By necessity the changes to the control system design or display format take place after the plant is operating or in the next plant design.

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In order to successfully meet the challenges presented by these changes, a new methodology for designing operator interfaces will be required in the process industries (Hijnsdorff, House, 1977). This approach will have to consider the functional requirements of the operator first rather than thinking initially in terms of the physical devices (displays, controls, etc.) and letting the operator's procedures be dictated by them. The considerations involve minimizing the human operator's exposure to emergency and stress situations yet giving him a job to perform for which he remains attentive at all times. One may expect that there is an optimum between "too much" and "too little" to do. Additional trade offs between performance and mental load will also have to be made.

To this end, some first actions are already being taken:

- Some companies have included control system and display designs as part of the first phase of process design (Figure 6) which better ensures their harmony with plant operational goals (Maverstock, 1976).
- The International Purdue Workshop, through its IHI committee, has issued guidelines for HMI/Operator interface design that emphasizes the operator's functional requirements (Purdue University, 1975).
- Some commercial displays have become available that have a functional design as their basis (Riz, Simba, Williamson, 1977).
- The problem of acceptance of new technologies and techniques that increase the level of control or management automation are being studied (Maverstock, Bernard, 1977).

III THE NEXT GENERATION OF MAN-MACHINE INTERFACES DESIGN

The traditional method of operator interface design will have to change in the future to reflect new directions and philosophy in plant operations. Some of the driving forces are:

- Technological changes in electronically driven displays such as CRT's and the advent of microprocessors have increased the pressure to use these devices to solve some of the problems of the panel. Early attempts were not successful, however (Kitchenska, Williamson, 1977).
- Energy and environmental problems are forcing plant managements to require operators to consider other concurrent objectives in addition to maximizing production at specified yield.
- Changes in plant seniority procedures have led to a higher turnover of process operators with resulting change in work load and training levels.
- The introduction of sophisticated processing plants in emerging countries, an unskilled labor force requires changes in the roles the operator control system play.
- The increased responsibility and disaster potential given operators in terms of the number of control loops and emergency actions are nearing the limits of mental loading (capacity).

FIGURE 5: THE DESIGN APPROACH FOR PRESENT CONTROL ROOM DISPLAYS

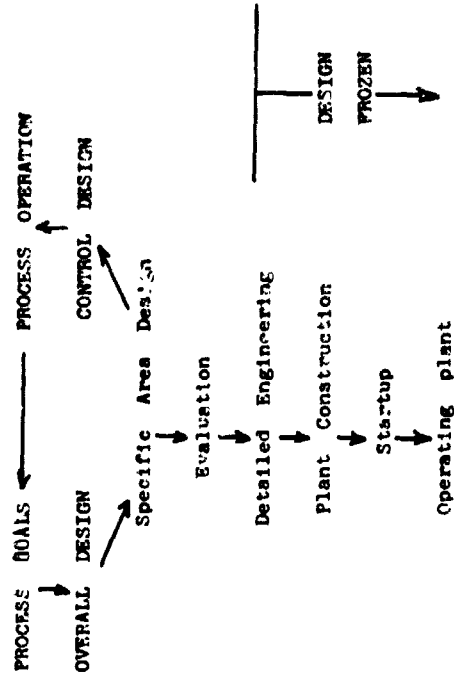
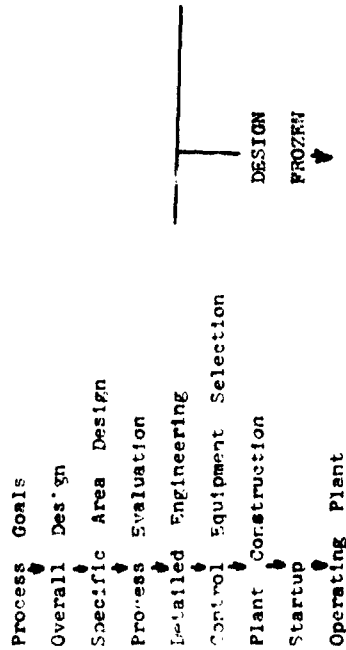
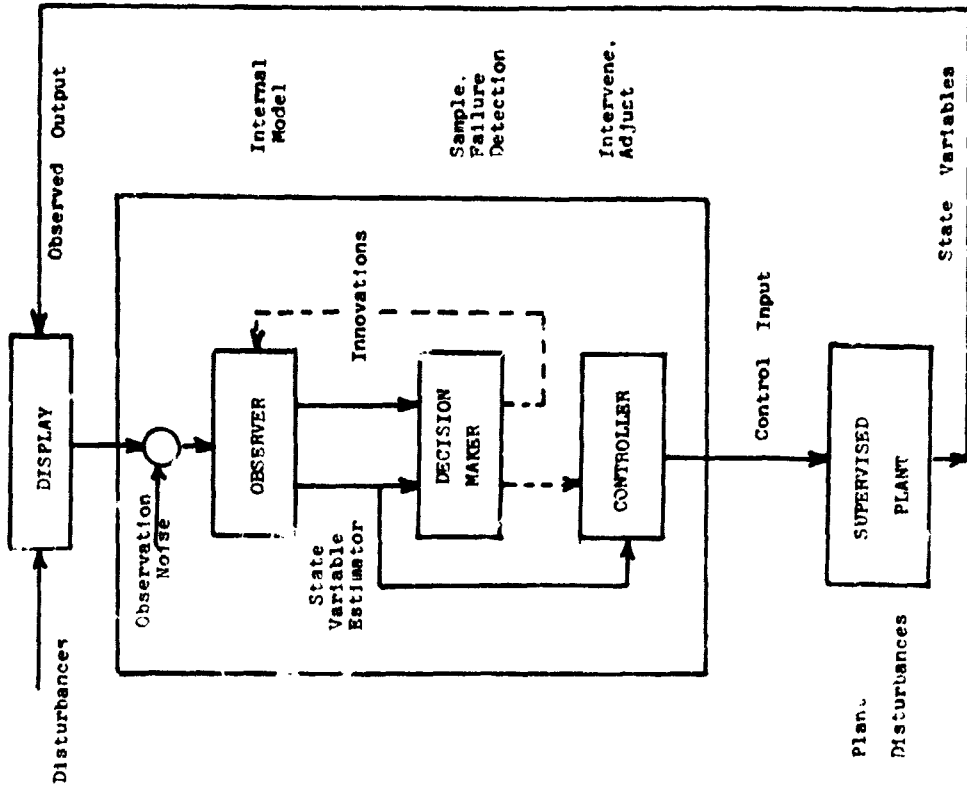


FIGURE 6: THE RECOMMENDED DESIGN APPROACH

FIGURE
Optimal Control Model
of the Human Supervisor



These directions are encouraging but still more is required. A much more fundamental approach is necessary. We therefore suggest to model the human operator's behavior in such a way that we can explain and predict to what extent task requirements, system design, disturbances, etc., may affect his performance. This approach follows the many manual control models which have been generated over the past few years for other cases of human supervisory control (Annual Manual Conferences, 1966-77).

In reviewing these we can distinguish two different types of models:

- Descriptive models, i.e., empirically testable models based on some criterion of fit of human input and output data.
- Normative models, i.e., models whose structure is proposed based on a norm or mathematical description and whose parameters are consequently estimated by the human input and output data.

Although most models are of the first type, these models only describe a human performance result - any attempt to explain why a man behaves like the model is not made. An important example of the second type is the cross-over model based on the describing function method (McQuee, Krendel, 1974). This model however can only be applied to the control of low dimensional systems.

The normative models, however, may be expected to contribute much more to the understanding of the performance of human supervisors since this type of model can be used to verify the action of the human operator. Among the many normative models proposed, such as the decision model (Elkind, 1968) and the model to describe a helmsman's behavior during supertanker control (Veldhuisen, 1976), the most general one is the optimal control model (Baron, Kleinman, 1968). This very general model can also be applied to multivariable, time-varying systems such as found in the process industries.

The model is based on the assumption that a well-trained human controller behaves in an optimal manner taking into account inherent human limitations, constraints, and task requirements. In control engineering terms this means: human beings are optimizing a certain criterion. They possess an internal model of the system dynamics, of the system noise and of the task requirement consistent with degree of training or experience they have.

The model mainly consists of two parts (Figure 7): (1) An observer which estimates the minimum variance estimate of the system under control from the displayed information (taking into account observation noise); and (2) A controller and decision-making element that generates setpoints and that decides whether the operator should take over the plant manually due to possible system failures. Hence, the model is capable of describing the following human supervisor functions: monitoring; failure detection; setpoint generators; manual control or intervening. Through these functions it would be possible to analyze the human operator's ability to control a process plant considering the basic structure of his goals, assigned tasks, knowledge of the process, degree of interaction with the control equipment and the information displayed. Specifically the modeling effort can address: The accuracy of the operator's internal model in making control decisions; the speed at which the operator changes his model under emergency conditions; the relationship between the information displayed and the dynamic reconfigurability of the internal model (including

possible saturation effects of too much data); and the relationship between the displays used and the measure of performance. An important feature of the model is the direct relationship between the psychological functions of the human supervisor and the subsections - observer, controller an decision maker - of the model (Kok, vanWijk, 1977).

The task of using the internal model to describe the behavior of a human operator as part of the man-machine system in the process industries is just beginning. The experience in applying the modeling technique is expected to reveal as much about the operator himself as the power of the internal model approach.

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