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HUMAN-COMPUTER INTERACTION IN THE NEW PROCESS TECHNOLOGY

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Abstract:
Systems technology has been changing its targets to meet the needs of the times. This paper discusses human-computer interaction in plant operation from the systems engineering viewpoint. Human-centered automation in the process industry requires the fusion of computer technology, cooperation technology and observations in cognitive science.

Keywords:
Plant Operation, Human Operator, Human-Centered Automation, Human-Computer Interaction, Cognitive Science, New Systems Technology

INTRODUCTION

In the recent information society, system complexity and the importance of software are increasing. A large complex system includes both humans and computers to control and manage the system. This means that such a system is a combined computational system, composed of the human and computer computational systems.

Plant operation involves a high degree of interdependence between process equipment, control systems and human operators. Flexible production in the process industry is greatly owing to operator control skills and intelligence. In this situation, computer aids in various forms are essential in solving operational problems. When we consider computer aids, we must take into account the operator's mental satisfaction. That sense of satisfaction is an important factor designing a system. This means that computers are not substitutes for humans, but are used to assist humans.

In the manufacturing system, automation often creates black-box processes with more sophisticated computer control systems. But some tasks will not be automated for various reasons, such as cost performance and safety. This will result in many isolated islands of automation, imposing a severe burden on the operator.

There are two approaches to this situation. One is to clarify the operator's tasks under specified circumstances and provide appropriate training; the other is to develop an operator-friendly, computer-aided operation support system for commercial operation. This paper considers human-computer interaction in plant operation and training from the systems engineering viewpoint.

PLANT OPERATION ISSUES

A comprehensive control and instrumentation system with distributed CPU, called DCS (distributed control system) has been used in the process industry since the 1970's. The DCS is a customized computer for system control. CRT operation based on the DCS brought accurate and stable conditions to plants, using sophisticated computer control technology. It realized higher quality products, energy conservation, yield increase, and so on. It also saved space and labor in the control room. However, it also generated new problems in plant operation.

Recently, several surveys on plant operation have been published in Japan [1-4]; This implies that plant operation is a crucial issue for the Japanese process industry. A survey states the future of plant operation as follows [1]: Broader duties must be carried out by fewer operators, using more sophisticated control and related technology.

The operator has many tasks, such as to keep the process running as closely as possible to a given condition, to preserve optimality, to detect failures, and to maintain safety [5]. In most plants, the operator must have not only control skills but also comprehensive knowledge and techniques, such as process maintenance and facility management.

The performance of skilled operators is represented by a three-level model, as shown in Fig.1 [6]. This model can be used to plan operator support and training systems. It is important that the operator be able to use a logical approach to understanding the state at the time. He should consciously reason out the meaning of things, analyze the situation, and make a rational decision. This approach enables the operator not only to take over conventional control skills but also new skills via computer aid, for coping with unexpected situation and realizing more flexible operation of the production system.

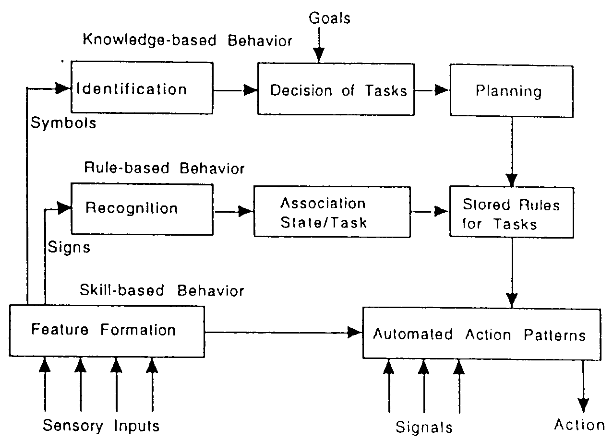

Fig.1 Three-level model of skilled human operator

TRAINING ISSUES

In the process industry, training simulators were first introduced to large continuous plants, such as refineries, power plants and town gas production plants. Simulation training is credited as a significant factor in diminishing accidents. A recent survey on operator training systems, that reviewed 20 training simulators in the refining, petrochemical and chemical industries in Japan, summarizes objectives, hardware, software, training contents and so on [3]. Generally, simulation is reportedly very useful for operator training.

In CRT operation, the operator can get information only via CRT. The first objective of the training simulator is to acclimatize operators to the computer operation environment. First, the operator must master screen manipulation on the CRT at the operator station. Second, the operator must learn special procedures for unusual operation, such as startup and shutdown of equipment items, and for emergency operation.

The operator cannot easily visualize what is happening in the processes. Therefore, computer aids for visualization of the process state are crucial for intuitive understanding. Steady-state process simulation helps system performance understanding and qualitative process simulation helps dynamic behavior understanding.

The training simulator can also be used to improve the man-machine interface of the operator station. For this purpose, the behavior of trainees at the operator station must be observed carefully and analyzed. Observations on cognitive and understanding processes will be useful in improving the interface. Also, new information technology, such as media technology and virtual reality technology, will help cooperative human-computer interaction. These techniques enhance operator control skills; the resulting improvement in the man-machine interface will help lessen human error.

ENGINEERING ISSUES

In the training simulator, on-line simulation is used to experience operating problems and take timely corrective action. Therefore, the system should be capable of accurately representing startup, shutdown and emergency conditions at an operator station. This requires dynamic, interactive, process-specific models over broad operating ranges. Combined discrete and continuous process modeling in particular is essential for representing actual plant operation.

The sequential control system is a typical example of the combined discrete and continuous process system. Figure 2 shows the system structure, including controlled object, sequential control equipment and operator [7]. The controlled object, called outer system, is composed of the processing equipment units and regulatory control system. The dynamics are represented by the continuous state equations. On the other hand, actions by the sequential control equipment and operator are described by a set of rules. The event-driven, discrete system is called inner system. The dynamics are represented by the discrete state equations. The method of modeling and analysis of the sequential control system can be used to examine the behavior of the combined discrete and continuous process system.

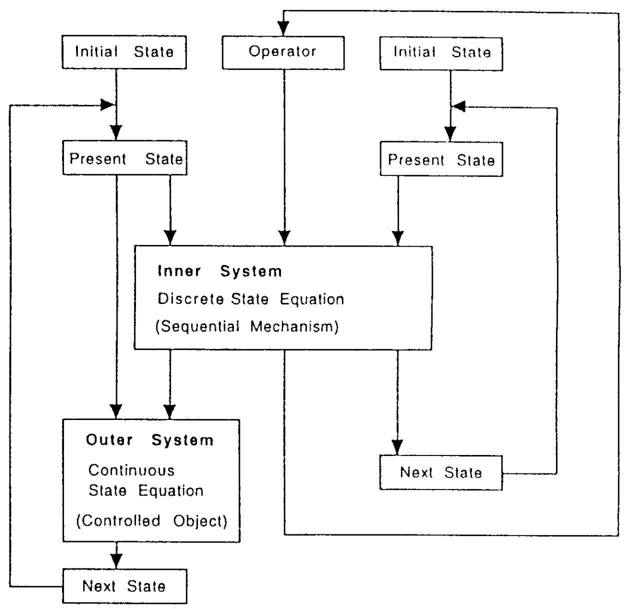

Fig.2 System structure of sequential control

Popularization of object-oriented programming and graphic user interface for workstations has been changing the modeling and simulation environment. The progress of software engineering in computer science stimulated research on modeling tools in chemical engineering in the mid 1980's; the objective was to support the rapid modeling and easy maintenance of models.

Object-oriented simulation is an indispensable technique for rapid development of application systems. Today, various commercial modeling tools can be used to construct custom-made simulators for existing plants. The combination of this kind of simulator and actual control systems offers a fundamental research environment for solving problems in plant operation and system design.

The fact that simulation is widely accepted for operator training is very significant. Plant models used in the simulator can be a common interest for engineers and operators. Communication between engineers and operators will afford better understanding of the processing system at the design and operating phases. The operator can know design intention and the engineer can recognize operational problems. Through cooperative work, problems will be found and effectively solved. This is an example of concurrent engineering in the process industry. Computer-supported cooperative work is also an important theme in plant operation.

HUMAN INTERACTION ISSUES

In the 1990's, it is widely recognized in the systems engineering that the human is an important system component and that the performance of a composite of human and computer should be evaluated. As a result, coordination and cooperation between humans and computers is being investigated by many researchers.

Man-machine interface has been studied in ergonomics or human engineering to optimize systems composed of humans and machines. In this approach, the human is regarded as responsible physiological equipment. On the other hand, mental responses in intellectual tasks, including pattern recognition, memory, problem solving, deduction, linguistic theory, were the focus in cognitive science. Ease of use, understanding and learning have been studied as user interface research in this area. Cooperative interaction between human and computer is under vigorous study.

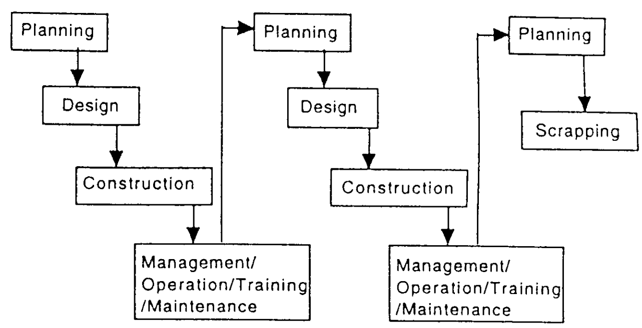

Fig.3 Life cycle of system

Any system has its life cycle, as shown in Fig.3. The target of systems technology is to support human activity at every phase in the life cycle. Each phase has human interaction issues to be solved, as follows [8,9]:

Planning Phase:
Up-stream activity of design, such as conceptual design and feasibility study, should be supported by computers. For this purpose, free access to necessary information is essential. At the same time, the security of the entire information system must be guaranteed.

Design and Construction Phase:
The size of software for operation control and management is increasing enormously. A system failure caused by software bugs can fatally damage the system. Therefore, the transmission and inheritance of engaged technology is a key factor in maintaining and improving the system. To this end, the design intention must be correctly described or symbolized by the designer. It must also be transferred from the design team to the maintenance team.

Management Phase:

It is important to grasp the present status by acquiring up-to-date data and to make a correct decision based on appropriate information. For this purpose, an efficient information retrieval system is required. Computer aids for the cooperative work of experts are also required.

Operation Phase:

In the automated system, computer systems cover their favorite subjects. On the other hand, a human is in charge of comprehensive judgment. In this situation, the roles of human and computer must be balanced. Also, the following instructions should be considered in designing a human interface:

- Indicate intuitive information on what is happening
- Indicate essential information on what is happening (This is to avoid operator mental overload.)
- Giving suggestions according to operator's experience and skills

Training Phase:

An operator must experience operating problems and take timely corrective actions. Operational skills and understanding of system behavior are acquired by on-the-job training and simulation training. To cope with unexperienced situations in a large system, logical understanding based on the principles of the phenomenon is essential for maintaining system integrity and ensuring system survival. To this end, an educational interface is needed to support human understanding.

The above-mentioned issues cannot be handled by the traditional systems technology. A new systems engineering approach is required to solve many problems involved in the human interaction issues. Superior human-computer interaction can generate an intelligent manufacturing system.

HUMAN-CENTERED SYSTEMS TECHNOLOGY

The aim of systems technology is to support all activities in the system's life cycle. Cooperation between humans and computers is essential to achieve this. Humans and computers both have their strong points. Each has its allotted tasks. A human is good at circumstantial judgment and pattern recognition. He can detect signs and interpret them. He can also exercise common sense and avoid conflicts. On the other hand, a computer is superior in solution-searching ability to the human.

Researches on task allotment and computer support for humans are now under way. Systems technology aimed at cooperation between humans and computers requires the integration of observations on the human cognitive process and computer technology. The new systems technology is composed of the following three components [9]:

Computer technology:
- Simulation and optimization technology
- AI technology
- Media technology
- Artificial reality technology

Cooperation technology (Groupware):
- Computer supported cooperative work technology
- Self-organization technology

Cognitive science:
- Observation of human cognition and understanding

The problem-oriented approach is recommended for developing a system. The general procedure is summarized as follows: First, the object problem must be analyzed carefully. Then, an appropriate solving method is determined by taking account of the characteristics of the problem. It is necessary to customize a general method for solving the actual problem. To this end, information on available methodologies and technologies should be shown on the screen; computer tools that support design should also be provided.

Modeling and simulation techniques are being developed in traditional engineering disciplines. The designing of systems for plant operation and training requires integration of process engineering (chemical engineering) and new systems technology.

OBSERVATIONS IN COGNITIVE SCIENCE

Interface Model

When we consider a man-machine interface or a computer support system in plant operation, a basic model of interfaces is useful in identifying the problem location. There are several interfaces for plant operation, as shown in Fig.4. Each has the following design instruction [8,10]:

Interface I: between user and object
WYSIWYW(What you see is what you want)
Interface II: between object and environment
WYSIWYG(What you see is what you get)
Interface III: between user and object
WYGIWYW(What you get is what you want)
Interface IV: between users
WYSIWIS(What you see is what I see)

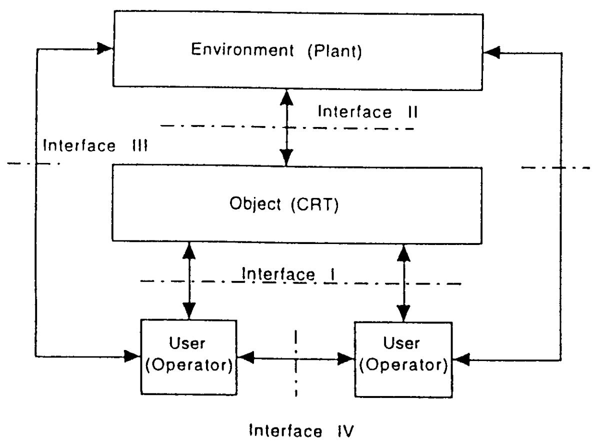

Fig.4 Interfaces of plant operation

Operator's Tasks in Human Supervisory Control

Figure 5 shows a model of supervisory control. It was proposed as representing the configuration of tele-operation remote control of a vehicle on the moon from the earth. There are two computers between the controlled object and the operator. A task interactive computer (TIC) is near to the controlled object and a human interactive computer (HIC) is near to the operator.

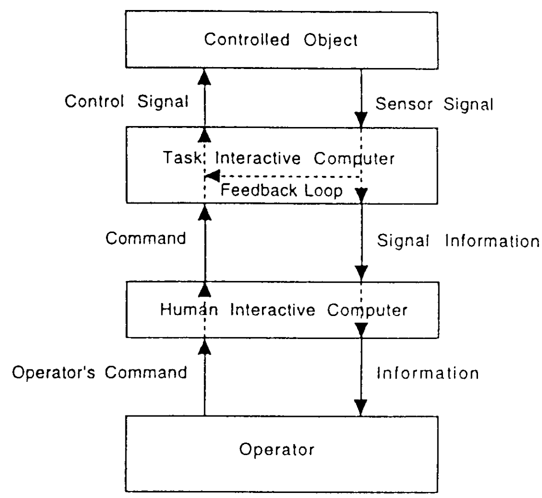

Fig.5 Model of human supervisory control

This model can be used to show many man-machine configurations, such as in manufacturing processes, nuclear power plants and aircraft. The operator's tasks in supervisory control can be classified into the following five groups [11]:

Planning: An action is planned by the operator to achieve a specified goal.

Instruction: The plan is input to the HIC by command or programming.

Supervision: The operator monitors the object, to determine whether the object is controlled as planned and whether any abnormal state is occurring.

Intervention: If the goal has been achieved, the operator gives a command to the HIC to set up a new goal. If an abnormal condition is detected, the operator intervenes with the TIC to remove automatic control.

Learning: The operator learns for the next such event.

Figure 6 shows the sequence of operator's tasks. This task sequence model is used to pick up human errors on recycle paths and to study how to cope with the situation.

Pedagogical Interface

A pedagogical interface was proposed to facilitate human understanding by some means [12]. Figure 7 shows the structure of a pedagogical interface. Such an interface should include functions to repeat problem description and explanation, to use another person's opinion and knowledge and to make cut-and-try experiments in the virtual environment. To this end, it is necessary to integrate new technologies such as hypermedia technology, groupware technology and virtual reality technology.

In particular, hypermedia technology, which shows information structure by nodes and links, enables information management of various kinds of communications media including text, image and voice[13]. This technology will provide a basic means of inheriting the knowledge and know-how of the skilled operator. This kind of interface is desired for operator training. It will be also used to pigeonhole various kinds of knowledge input by many experts.

The combination of hypermedia and simulation, called hyper-simulation, facilitates different types of understanding, such as experiential understanding by simulation, logical understanding by theory and intuitive understanding by image [13].

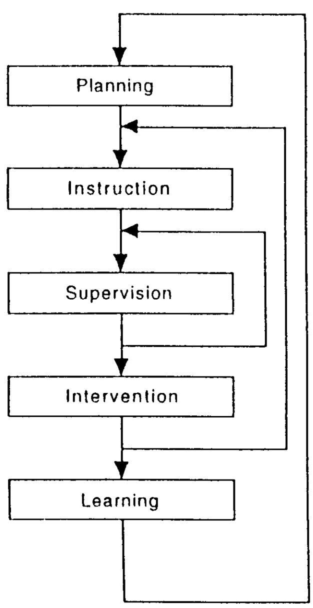

Fig.6 Sequence of operator's tasks

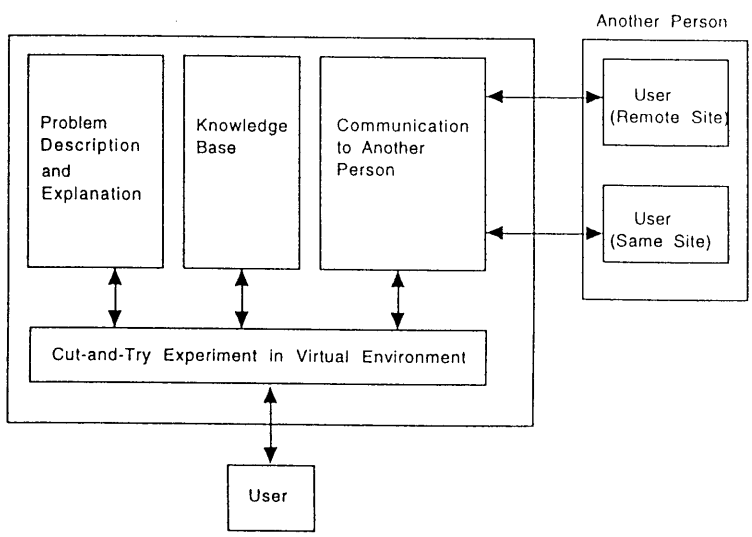

Fig.7 Pedagogical interface for understanding support system

CASE STUDY OF HUMAN-COMPUTER INTERACTION

A combined batch/continuous plant generates difficult operational problems because both discrete and continuous dynamics must be considered in decision making. To resolve these problems, dynamic simulation that predicts plant-wide states can be run. An operation support system with operational guidance was derived from the model predictive control concept [14]. The basic idea of model predictive control is easily understandable for the operator and is widely accepted in process control.

Figure 8 shows the process flow of the objective plant. The cause and effect of operational problems concerning the plant are summarized in Fig.9. The structure of the operation support system is shown in Fig.10. In the system, the flow controller's set-point values are implemented by the operator. Automatic implementation of set-point control eliminates the need for an operator; however, operational problems such as batch reactor discharge wait and idle operation of continuous units will still occur under uncertain conditions because of the limited flexibility of plant capacity. In such a situation, an operation support system is useful for coping with various irregularities.

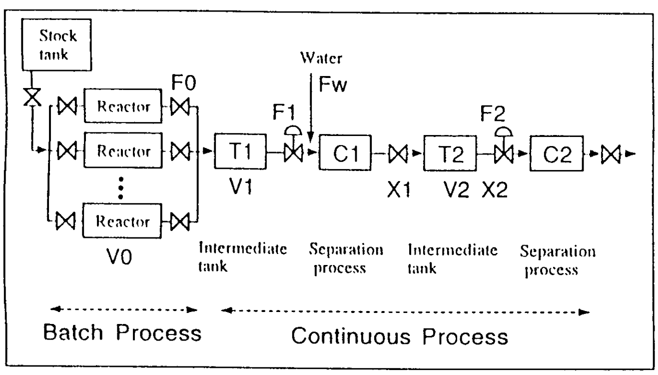

Fig.8 Process flow of combined batch/continuous process plant

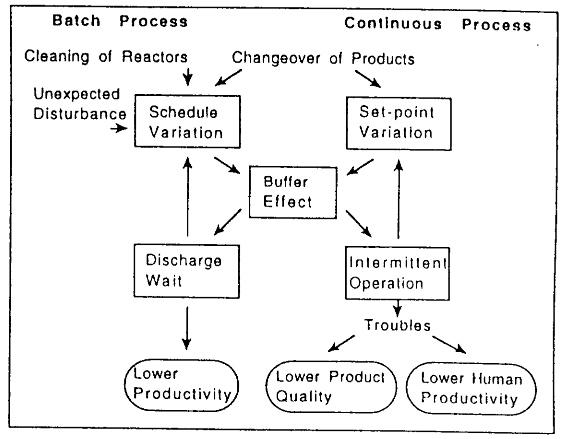

Fig.9 Operational problems in combined process plant

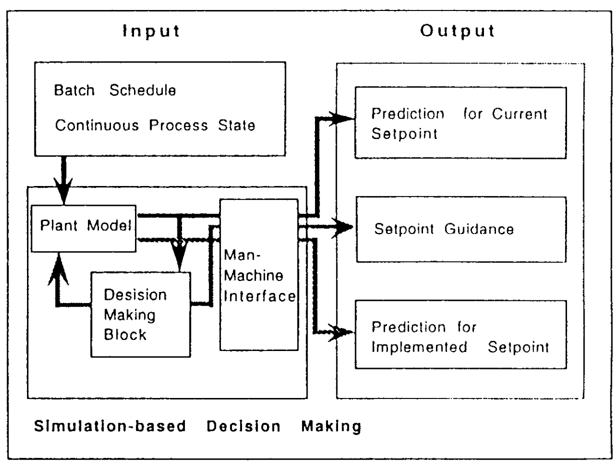

Fig. 10 Structure of operation support system

This system allows operators to enter optional values of flow-rates and shows them simulation results. The man-machine interface is important for effectively informing the operators of the results. The proposed operation support system, implemented in an actual plant, yielded considerable productivity increase and continuous unit stability.

CONCLUDING REMARKS

Human-computer interaction is a key issue in providing synergistic production in a safe and comfortable manufacturing environment. Observations in cognitive science should be effectively used to design a human-centered production system with cooperative human-computer interaction. In this paper, the present status of plant operation and training was reviewed and future research needs were identified.

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