Short survey of research activities

Research
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Research Group on Man-Machine Systems
Department of Industrial Engineering
Eindhoven University of Technology

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P.H.Paternotte (editor)

Preface

This report describes the research activities conducted in the field of man-machine systems at the Department of Industrial Engineering of Eindhoven University of Technology (EUT).

The first section serves as an introduction to the backgrounds, aims of the research actually in hand and of current research topics.
The second deals with the research themes in greater detail.

More specific information can be obtained from the chairman of the research group

Mr. H. Kragt
Department of Industrial Engineering
Paviljoen U13
Eindhoven University of Technology
P.O. Box 513
Eindhoven
The Netherlands

Contents

1. Introduction

The Department of Industrial Engineering of the Eindhoven University of Technology has been involved since 1971 in field research on the human operator in complex systems. On its inception the research was centred on the skills required of operators and on developing methods to describe operator functioning both in normal operation and breakdown situations (see Kragt and Landeweerd, 1975).
Gradually the need was felt to expand these activities to allow the methods developed to be used in the design or redesign of existing and future man-machine systems.
That is, to be able to optimize such systems with respect to technical, economic and social criteria.
A number of engineers and psychologists therefore decided in 1973 to combine their efforts, establishing a more-or-less informal "Research Group on Man-Machine Systems". Expert advice was and is provided by professors in control engineering and industrial psychology.
At the same time contact was made with similar research groups of the Twente University of Technology and the Netherlands Institute of Preventive Medicine/TNO with the aim of exchanging mutually valuable information and, more important, to ensure that each research group would focus its attention on a different part of the man-machine systems problem area.

Field research is carried out at the Chemical Works of the Dutch State Mines (DSM). The special focus on chemical processes is due to previous contacts and the geographical positions of EUT and DSM.
In addition, a laboratory simulation of a real distillation process was developed, in digital form, and has recently become operational. The purpose of this particular simulation is to assess the possibilities of simulation research and to answer a number of questions on real situations that cannot be answered by field research due to the uncontrollability of independent variables.
Should the simulation studies prove succesful the aim is to expand such research by simulating a greater number of (interacting) processes and constructing more complicated control and monitoring tasks, thus covering a broad range of human operator tasks.
At the moment the following research and development project are in progress:
- Classification of tasks and abilities;
- Information and (control) performance;
- Human reliability;

- Internal representations;
- Workintrinsic satisfaction;
- Software development for ergonomic experiments.

The following section deals with these topics in more detail.

2. Research Topics

2.1. Classification of tasks and abilities

Obviously, the benefits of research by the working group will be greater as the results can be applied to a wider diversity of control tasks.
We shall seek for, or construct, two classification systems to serve as a sólid base upon which research results can be generalised.
The kind of systems we are looking for are referred to under many names, which have little, if any, relation to their formal properties or applicability. We define a classification system as a set of (at least nominally) ordered categories in terms of which all objects in a defined set can be objectively described.
Different objects (e.g. a simulated process and a real process) can be compared when they are described in terms of the same classification system. In this case observations carried on one object can be generalised with reference to the other.
In addition to the possibility of arriving at well-founded generalizations, classification systems make for smooth communication between researchers, and greater accessability of research results.
A classification system as defined above must allow the ordering of tasks.
With Miller (1967) we define a task as any set of activities occurring about the same time, sharing some common purpose recognised by the task performer.
The second classification system will be concerned with abilities. For a definition of ability we refer to Fleishman (1967, b) who makes a distinction between the concepts of ability and skill. Ability refers to an individual's general traits, which can be inferred from behaviour displayed in several tasks, e.g. spatial orientation. Skill refers to a specific aptitude to perform a task or a group of related tasks. Fleishman (1967, b) assumes that as skills are much more complex than abilities, they can be analyzed into abilities.
For an example of a classification of abilities, see Berliner (1964).
The classification system we need must possess the following characteristics:
a. tasks can be described objectively in terms of the categories;

b. the categories are closely connected to the theories and concepts commonly used in the behavioral sciences.

In the literature reviewed thus far we found no classification system meeting these requirements.

The taxonomic studies carried out at the American Institute for Research (Fleishman and Stephenson, 1970, Farina and Wheaton, 1971, Levine, Romashko and Fleishman, 1971, Teichner and Whitehead, 1971, Theologus and Fleishman, 1971) are concerned with psychomotor tasks, typically not exceeding a cycle time of some minutes.

We doubt it the operator's tasks in which we are interested have enough in common with these psychomotor tasks to be covered by the same classification system. These doubts do not apply to Berliner's (1964) classifcation system, but here the problem is the lack of objective means for scaling the observations.

The development of our classification system will be based partly on field studies. In this research we shall try to find the relevant categories by combining information from two sources. The first source is the operators behaviour, the second the reasons for that behaviour, the goals aimed at, etc.

Data will be collected by observation, interviewing the operator, his supervisor etc.

2.2. Information and Performance

The purpose of this research is the assessment of qualitative relations between information nature and quantity presented, control behaviour and control performance.

Because of the lack of control on independent variables (e.g. process disturbances) in real situations the greater part of this research project will be carried out in the laboratory using a high-fidelity simulated distillation process.

The dependent variable, control performance, was explored in a series of preliminary simulation and field studies (see Paternotte and Verhagen, 1976). Some quality, quantity and combined criteria were carefully chosen so as to fulfil the following requirements for valid performance measurement:

1. criterion clear to operator;
2. criterion realizable by operator;
3. performance score (criterion score) clear to operator;
4. real criterion (corresponding to industrial standards).

The independent variable, the information presented on the operators panel, is created in several ways.

A. A theoretical framework is put forward to quantify the information presented in communication-theoretical terms. This approach is related to the methods used by van Gigch (1970a, 1970b, 1971a, 1971b) and Nadler and Seidel (1966).
   The major drawback to this approach is the fact that the uncertainly concept applies only to completely layman operators who really are uncertain about every scale reading and who will therefore collect as much information as they can. However, operators with some experience will have different information needs because they are able to derive all the information necessary to control the process by taking a few cue readings. In general terms: there is a certain amount of redundancy but the amount is a personal matter.
   For that reason special measures will be taken to control the effects of subjective uncertainty.
B. A well-known method as described by e.g. Drury and Baum (1976), is to vary information presentation by displaying:
   1. time-history information (feedback history);
   2. intermediate information (cues for prediction);
   3. input information.
C. Information can be varied by accuracy of presentation and by varying the presentation rate (continuous vs intervals differing in length).
D. Information can be converted, e.g. by presenting derivatives or integrated values of process variables.
E. The display type can be varied from the well-known conventional types (dials, moving pointer, fixed pointer, etc.) to sophisticated CRTs.

The control behaviour will be used to explore the relations between information and control performance.
The subjective uncertainty concept will be dealt with by observing the operator's sampling behaviour and his control actions.
The sampling behaviour will be followed by trained observers equipped with a fast data-entry keyboard connected to a portable cartridge recorder with a digital read-out option.
If possible the sampling behaviour will be described with models as presented by Crossman (1964), Senders (1964, 1966, 1969) and Sheridan (1970).
The control actions will be recorded (on-line) with reference to a number of parameters (see Paternotte and Verhagen, 1976).

The final aim of this threefold approach is to develop criteria for information design in process control with respect to specific human capabilities with a view to optimizing system performance.

2.3. Human Reliability in more-or-less Automated Man-machine Systems

When systems reliability is under discussion in literature, in most cases the reliability of the technical system is meant. Since, however the technical system is still controlled by the human operator in many situations, one has to investigate human reliability as well. By so doing we deal with the reliability of the whole man-machine system. Whether it is possible to estimate the human reliability in the above mentioned systems cannot as yet be said. A number of factors are known to effect human control performance, and hence human reliability. Moreover, these factors are totally different from those that influence components of the technical system. In the investigation we should not restrict ourselves just to a task analysis (what is the operator doing?), but should also do a skill analysis (how is he doing his task?), because we are not only interested in questions such as, what is the operator's error?, and what is the risk of that error?, but also in questions like, why and by whom was the error made, and in what circumstances?

As human unreliability is related to the probability of human error, one of the first things we will have to do is to define the concept of "human error" in our situation. That situation is, as has already been said, that of the human operator controlling a distillation column. We can describe the task of such an operator as follows:

1. monitoring the process;
2. adjusting the process (after the occurrence of a disturbance);
3. minimizing the effects of breakdowns;
4. shutting down and starting up the process.

We should like to do research in our laboratory, especially into situations in which disturbances and breakdowns occur.

Before we can do so we shall have to start with an investigation in the field to study the control behaviour of operators in such situations by means of the critical incident technique.

After such field research we shall investigate that behaviour in more detail in our laboratory.

In the foregoing we have roughly sketched some ideas on human reliability.

At the moment (July, 1976) a paper is being prepared for presentation to the symposium on Human Operators and Simulation, in Loughborough (U.K.) on and 29-31 March 1977. This paper will deal with the subject and the research plans in more detail.

2.4. Internal Representation

It is assumed that process controllers form an internal (mental) representation of the processes that they control.
Two forms are commonly distinguished:
- the mental model of the process (i.e. the internal representation of how the process functions);
- the mental image of the process (i.e. the internal representation of the process structure).

A number of factors are related to the quality of such an IR.
The main ones are shown in figure 1.

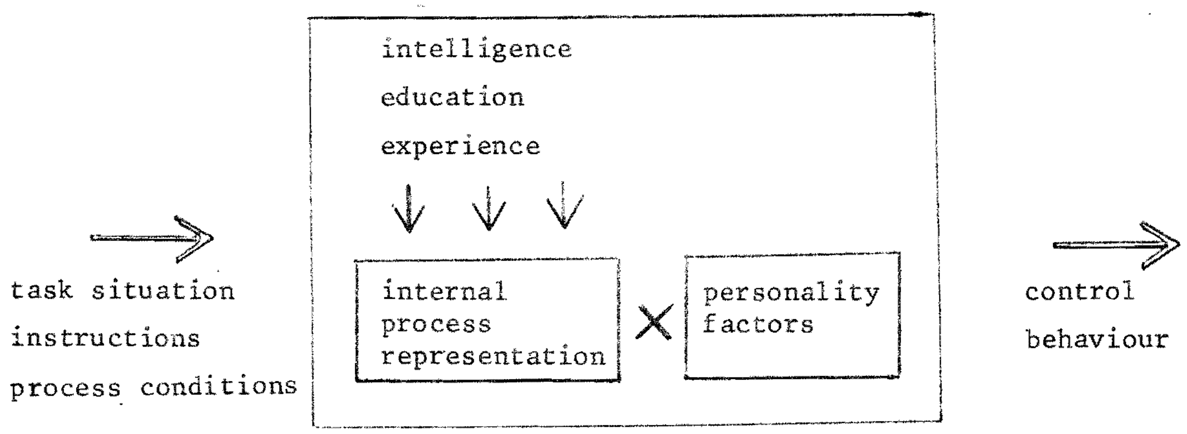

Figure 1. Important factors related to internal representation.

The relations from figure 1 will be investigated in a research project at the DSM chemical industry. A pneumatic simulator of a distillation process at the training department is of vital importance.
The hypotheses that will be investigated can be divided into three categories, first those concerning the relationship between certain factors such as the intelligence, experience and education aspects and the IR quality; second,

those concerning the relationship between IR quality and control behaviour; third, those concerning the role played by personality factors.
The project will have roughly the following content:

1. Some 80 trainees will be given a standard instruction (both in the classroom and at the control panel of the simulator) concerning the control of this distillation process.

2. The quality of the mental image and mental model formed will be measured by means of a scrutinously designed questionnaire and visual aids.

3. The trainees are then asked to take part in a series of tests to measure aspects of control behaviour and control performance, two of which we mention below:
   - They are asked to do two tests at the control panel of the simulator. We are especially interested in their sampling behaviour of information points and in their actions at the controls. An observation method has been designed for the purpose. The two tests concern updating and minimizing the effects of a disturbance.
   - They are also asked to perform the so-called "slide test". In some disturbance situations slides of the control panel instruments have been made. Technical aids allow the panel to be projected onto an overhead projection screen. Every instrument can be withheld or shown at will. We confront the trainee with one instrument whose indication is off-normal. He may ask the experimenter to show him whatever other indicator he wants to see, until he can diagnose the disturbance. We are interested in his sequence of indicator requests and of course in his diagnosis.

4. Finally they have to do some psychological tests (intelligence, fear of failure, impulsivity, sensation seeking and others).

The data will be used to test hypotheses concerning the above mentioned relations as well as in more detailed analyses. Moreover, the consequences as regards display lay-out and training will be considered, the spin off probably being a number of questions for later research at the digital simulator of the distillation process.

2.5. Work-intrinsic Motivation

This research is aimed at finding ways to structure control tasks in such a way that operators can get maximum satisfaction from doing their work. The worksatisfaction of an operator can be derived from characteristics of the work itself, and from closely related factors of a social or financial nature. The research group will be looking for factors in the work itself which affect the work satisfaction of operators, or of certain kinds of operators. We expect the results of this research to improve task allocation, both between man and machine as well as between members of a team.

People differ in the degree to which they enjoy their work, probably because of variations in the degree to which their needs (the things they value) are satisfied by doing their work.
A number of factors can contribute to the satisfaction of someone who works. They motivate him when they are of value to him. In the positive case they may bring him into action and open the way to pleasure and satisfaction, in the negative case they cause dissatisfaction and perhaps absenteeism.
A well known frame of reference in the study of satisfaction is the difference between work-intrinsic and work-extrinsic variables.
Work-intrinsic factors are directly related to the task, e.g. length of a work cycle, opportunity for self development, challenge, etc. Work-extrinsic factors are connected with the work, but not directly with the task itself, e.g. payment, social security, contacts with colleagues and supervisors.
It is not always easy to classify a factor in one of the two categories, e.g. "social contacts" where the task has to be performed in close cooperation with other people.
We orient our research towards work-intrinsic factors for the following reasons:

a. a number of extrinsic factors cannot be influenced: in process control tasks many processes will be continuous, implying shift work and intensive contacts with other people;
b. the typical character of many of the individual process control tasks (e.g. relatively severe under- or overloading, heavy responsibility, decision making) in itself makes it necessary to study work-related factors for their relation to satisfaction.

Our aim is to find factors that can satisfy (some) people in process control tasks. Having found some such factors, we can try to make tasks more human within the limits discussed above.
Amendments to the operating instructions, changes in displays or controls, changes in the allocation of parts of the task to a number of people, etc. could con-

stitute possible changes in task structure.
In short, the research will concern itself with the measurement of satisfaction experienced by various people performing different tasks in different ways.

- Characteristics of people (abilities, needs) will be treated as intervening variables.
- Task characteristics (complexity of the technical system, clarity of instruction, autonomy) will be treated as either independent or control variables.
- Different ways of performing will be treated as control variables or as intervening variables.
- Satisfaction will be treated as a dependent variable when due to work-intrinsic factors. Satisfaction caused by extrinsic factors will be treated as a control variable or as independent variable.
  The task classification system described in (2.1.) will be very useful in dealing with task characteristics.

2.6. Software Development for Ergonomic Experiments

2.6.1. Introduction

For detailed investigations, for instance in the field of information presentation and human reliability (2.1. and 2.4.), a process simulator has been developed in the laboratory of the Department of Industrial Engineering. The heart of the simulation is a DEC PDP 11/40 minicomputer. An operator panel has been built in a noise proof air-conditioned control room. The Dutch Chemical Industries DSM kindly allowed us to use an existing static mathematical model of one of their distillation columns. This model describes input-output relations of the process without any dynamic responses. Dynamic responses, input, output routines and controllers have been added.

The software development project for ergonomic experiments has three main goals:

1. development and improvement of the simulation itself;
2. communication programs for experiment monitoring and interaction with the current experiment;
3. off-line and on-line data analysis.

The project is staffed by two electrical engineers who maintain simulation and communication software.

2.6.2. Description of the subprojects

2.6.2.1. Development and improvement of the simulation itself

a. The simulation of a single distillation column

The actual simulation consists of an overall static model with dynamic responses added. The consequence of this approach is that the simulation is only realistic in a restricted domain of normal operations. Start-Up, shut-down and breakdowns have to be added as separate routines.
A project, in cooperation with DSM, is planned for the development of a full dynamic model of the distillation process. A modular approach will be used, simulating different sections of the column in different blocks. Separate modules for discrete process conditions will also be developed. Interfaces between modules will provide for gradual take-over by one block from another.

b. Simulation of a complete control task

Medium term planning ends with the simulation of two main columns, one pre- and one post-distillation including buffer storage tanks. The same model will be used for each column, with dynamics adapted as required and operating under different process conditions. However, this plant will only be realized when a larger central processor and extended IO communication have been installed. A multi-tasking operating system will provide facilities for the simulation of advanced control sytems for the operator (CRTs, computer assisted control).

2.6.2.2. Communication with the experimenter

Since the operator is working in a separate control room, the experimenter must be able to follow the course of his experiment. At present he has a CRT facility with process diagram and process-state on it. Automatic logging of the experiment on teletype is being realized. Data are simultaneously stored on disk. Several ways of presenting information to the experimenter via CRT or teletype are being investigated.
Communication programs are flexible and interactive, allowing the experimenter to monitor and to modify the experiment. Starting, stopping the experiment and simulation of disturbances are some routines that have been recently written.

2.6.2.3. Data Analysis

a. Off-line analysis can be done on the final results of each experiment, such as are for instance statistical analysis of performance measures on subjects and trials.
A control action-analysis program has been written for off-line analysis of stored data.
One important feature is the inspection of variables immediately after an experiment, with the help of a data evaluation package called SPARTA, which is provided by the computer manufacturer. This allows a quick check on the quality of the stored material.

b. On-line analysis is done in the presently available single job operating system. Operator actions are recorded and performance measures calculated. In the available two-job operating system and in the future multi-tasking operating system it will be possible to view already stored data on CRT. Thus the experimenter can make his decisions on the basis of historic information.

2.6.3. Future Developments

With the new central processor already mentioned and a multi-tasking operating system a large set of tasks will be developed. First the simulation will be realized of a larger plant with several types of operator-control possibilities. An automatic experiment monitoring program to carry out a programmed experimental design will be useful in larger series of experiments.
A flexible set of programs for experimenters' interaction will then be needed for the many different types of experiments planned.
Special care will have to be taken for the long running vigilance experiments (software reliability) and the simulation of disturbances and breakdowns.
New, flexible techniques for data storage and data reduction are being developed.

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Verhagen, L.H.J.M. (1975) Computer Programs for data management and Experimental Control with a Simulated Process. Paper presented to the Second International Symposium on Man-Machine Systems and Environment, Dubrovnik 16-18 oct. 1975, Yugoslavia.

(These last two papers will be published in the symposium proceedings by the Yugoslav Ergonomic Society.)

Forthcoming

Kragt, H. (1977) Human Reliability in more-or-less Automated Systems. Paper to be presented to the Symposium on Human Operators and Simulation, Loughborough University, 29-31 March 1977, England.

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