ANALYSIS, DESIGN, & EVALUATION OF MAN-MACHINE SYSTEMS

Edited by
G. JOHANNSEN and J. E. RIJNSDORP

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PREFACE

The field of man-machine systems has grown rapidly during the last decade. It is now recognized and still expanding as the major interdisciplinary contribution of research and development to the improvement of the interaction of humans with all kinds of technological systems that more and more frequently include computers as an integral system component. Various aspects of human-machine interaction in such systems have emerged. These are reflected in the different sessions of the Conference. Task issues of interest are, among others, controlling, monitoring, decision making, fault management, problem solving, and planning.

The aim of the Conference is to present, discuss, and summarize recent advances in theory, experimental and analytical research, and applications, related to man-machine systems. The International Program Committee has made a careful selection of papers for the Conference. Three types of papers have been distinguished: Survey (S), Technical (T), and Interactive (I). All papers are included in the Proceedings in sequence of the 7 sessions of the Conference.

We hope that the result will be beneficial to all engineers and scientists in automatic control, information processing, operational research, and ergonomics who are actively working or strongly interested in the young field of man-machine systems.

G. Johannsen

J.E. Rijnsdorp

Editors

MAN-MACHINE SYSTEMS — INTRODUCTION AND BACKGROUND

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Abstract. This paper is an introduction to the IFAC/IFIP/IFORS/IEA Conference on Analysis, Design, and Evaluation of Man-Machine Systems. It serves as an umbrella for the survey papers and topic areas of the conference. Therefore, it is very broad in its scope and condensed in its exposition. The man-machine system is defined, its general purpose explained, and the multitude of application areas stated. The historical and scientific background of the field is briefly outlined. Human task categories in man-machine systems are described.

Keywords. Man-machine systems; manual control; optimal control model; supervisory control; operations research methodologies; problem solving; human-computer interaction; software ergonomics; human reliability; social effects of automation.

DEFINITION AND PURPOSE OF MAN-MACHINE SYSTEMS

A man-machine system is defined as a functional synthesis between a biological/psychological/social system (the man or a group of people) and a technological system (the machine) characterized predominantly by the interaction and functional interdependence between these two. All kinds of technological systems regardless of degree of complexity may be part of a man-machine system, e.g., industrial plants, vehicles, manipulators, prostheses, computers or management information systems. For the interaction with such systems, mostly psychological but also social aspects are of concern. Task categories like controlling and problem solving describe typical human activities in man-machine systems. Later on, these task categories will be explained in more detail.

The overall purpose of any man-machine system is to provide a certain function, product or service as an output with reasonable costs, even under conditions of disturbances influencing man, machine or both (see Fig. 1). The main goals or inputs of a man-machine system are expected values of performance, costs, reliability, and safety. At least since some spectacular accidents have occurred with aircraft and nuclear power plants, reliability and safety have become vitally important operational as well as design goals in addition to performance and costs; see Sheridan (1982). Also, an acceptable level of workload and job satisfaction of the man should be maintained; see, e.g., Moray (1979).

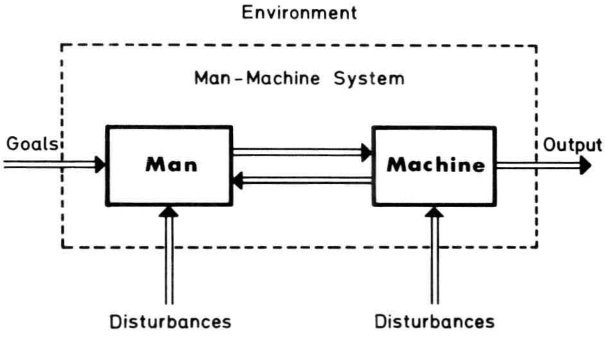

Fig. 1. Man-Machine System (MMS)

Some of these goals are in conflict with each other. Such conflicts have to be resolved in the most favorable manner by the designers of a particular man-machine system. Any deficiencies left to the human user of such systems may cause poorer performance, job satisfaction, and safety.

The interaction between man and machine is the essential aspect of a man-machine system. Classical ergonomic aspects like knobs and dials design, anthropometry, lighting, or adverse environmental factors have intensively been investigated. Many results are available, although not always applied appropriately. In contrast, the focus of attention has centered on informational aspects in the last years. Questions of concern to a successful interaction between man and machine are:

What kind of information is needed?

How should the information be organized?

Which information should be preprocessed?

How should the information be transmitted?

All of these or similar questions can arise in different application areas. The questions relate to the control of technological systems, namely, to the degree of automation as well as to the design of computer-generated displays with preprocessing capabilities. Further, they relate to all kinds of human-computer interaction as well as to management tasks on different organizational levels. The importance of the shifting from hardware and environmental aspects to software considerations is nowadays expressed by the new term software ergonomics.

From the preceding discussion, one can see that a wide range of technical areas is involved and contributing to the field of man-machine systems. Therefore, a conference dealing with the subject will necessarily be interdisciplinary in nature. Consequently, this conference is sponsored by four international federations which represent the most important disciplines concerned with the field of man-machine systems, namely IFAC (automatic control), IFIP (information processing), IFORS (operational research), and IEA (ergonomics).

HISTORICAL AND SCIENTIFIC BACKGROUND

A brief outline of the historical and scientific background of man-machine systems may further illustrate the growing importance of the field. The first existence of man-machine systems can be traced back into the early days of simple machines powered by men. With respect to human use, these were designed intuitively by experience. This is even today a very common method. With more complex and faster responding technological systems however, it turns out to be more and more mandatory in many application areas to use analytical and consciously applied methodologies and systematic techniques for the design of the man-machine system as a whole.

For about 40 years, methodological knowledge has been gathered and systematic techniques have been elaborated. Most of the first investigations of man-machine systems were concerned with manual control tasks, often applied to aircraft piloting, later also to ship steering, car driving, and industrial process control. This work was done either by experimental psychologists or by control, systems, and application-oriented engineers. Overviews and literature surveys have been given in several books: Kelley (1968), Oppelt and Vossius (1970), Edwards and Lees (1974), Sheridan and Ferrell (1974), and Johannsen et al. (1977).

Many control theoretic models were developed to describe the behavior of the human operator in manual control tasks. They have successfully been applied as design tools for automatic control systems which are better adapted to the human operator, for unburdening displays, etc. The most sophisticated and well validated model is the optimal control model shown in Fig. 2 in its basic form; see also, e.g., Johannsen and Govindaraj (1980) and Pew and Baron (1982). It is structured into (1) a perception and attention allocation part, (2) a central information processing part with an internal representation of the system to be controlled, and

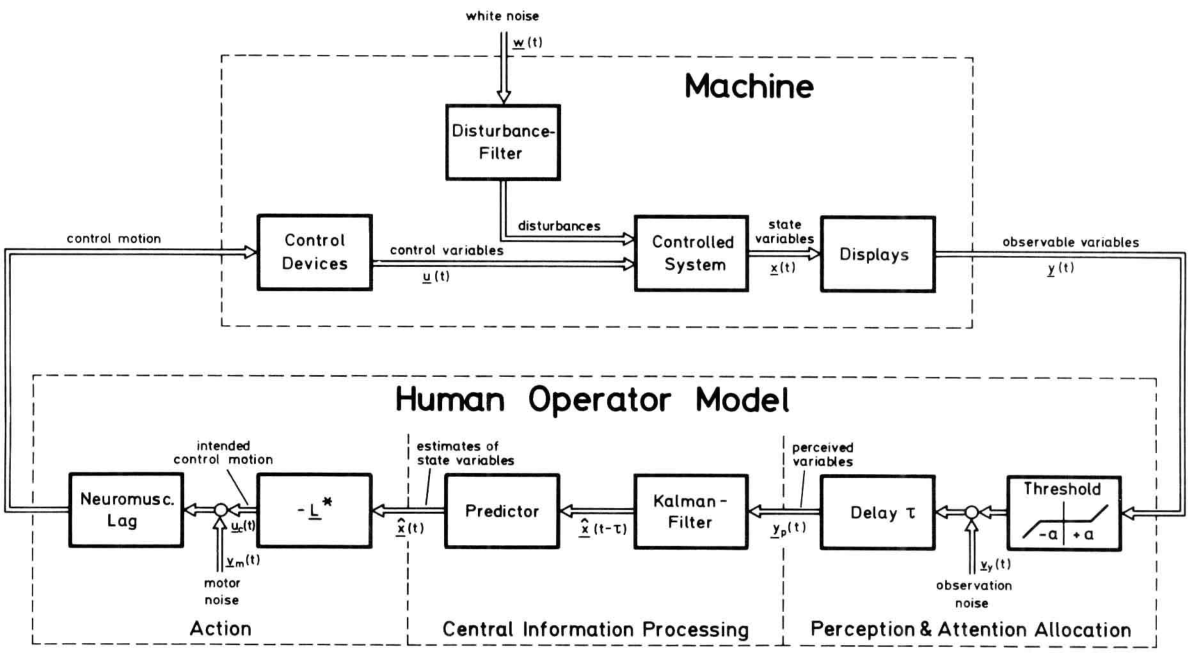

Fig. 2. Optimal Control Model

(3) an action part generating optimal control signals with respect to a cost criterion and based on the estimates of all systems states.

With slower responding systems like ships and industrial process plants, it became obvious that it is more difficult to explain the human operator behavior by well established control theoretic methods. The human control behavior is highly nonlinear and intermittent in these cases. Intrinsic monitoring, decision-making, and supervisory control behavior became evident and attracted the attention of several investigators; see Sheridan and Johannsen (1976). Some methodologies from operations research like network analysis and queueing theory have been adopted and comprehensive extensions of the optimal control model have been developed to describe broader human operator tasks as well as the whole design process for complex man-machine systems; see, e.g., Siegel and Wolf (1969), Pritsker and Pegden (1979), Rouse (1980), Moraal and Kraiss (1981), and Pew and Baron (1982).

Another root for the field of man-machine systems came out of what is nowadays called cognitive science, a combination of cognitive psychology and computer science. These sciences developed without any strong relationship to man-machine systems. Models of the brain, theories for memory and thought as well as human and artificial intelligence and problem solving have been investigated; see, e.g., Newell and Simon (1972), Klix (1979).

Task analyses show that problem solving tasks are more important than control tasks in many man-machine systems. Therefore, methodologies from cognitive sciences have been adopted for the analysis and design of these systems, but only since a few years ago; see Rouse (1982).

Technological advances such as computers and electronic displays have changed and will continue to change man-machine systems in almost all application areas. This is true for industrial plants used for production or power generation as well as for vehicles and transportation systems. In addition, office systems and information systems for observation, management, and command tasks in business, defense, and medicine are today simiarly influenced. Not only the operation of technological systems by highly skilled personnel, but also its use by inexperienced people like in mass transport, as well as the maintenance and design of systems are aided by computers.

A common problem to all these applications is the design of the human-computer interaction; see, e.g., Rouse (1981), Hatvany and Guedj (1982), Williges and Williges (1982). The possibly adaptive task allocation between man and computer, the dialog design including the use of natural language, and other software ergonomic aspects are nowadays especially important topics of research and development.

Also, the design of knowledge-based systems will lead to helpful tools in such areas as computer-aided decision-making, information retrieval, and fault diagnosis.

With more computerization and higher degrees of automation, new social effects and perspectives become evident. The advanced technologies allow a more flexible work organization with higher user acceptance and job satisfaction. However, this advantage can only be achieved if the social implications are considered early enough by the designers of future computerized man-machine systems; see Margulies and Zemanek (1982).

HUMAN TASK CATEGORIES

All tasks of human personnel in man-machine systems can be condensed into only two categories:

(1) controlling and

(2) problem solving.

These human task categories are fairly general. Fig. 3 shows an attempt to integrate them into a schematic block diagram.

Controlling shall here be understood in a broader sense than, e.g., in control theory; see also Johannsen and Rouse (1979). It comprises controlling in the narrower sense (including open-loop vs. closed-loop and linear vs. intermittent controlling) but also all other action-oriented tasks such as reaching and discrete-event acting (e.g., switching, typing). Only through controlling, outputs of the man-machine system to the environment can be produced (see Fig. 3).

In contrast to controlling, problem solving is an internal process on a higher cognitive level. It comprises different tasks, mainly, fault managing (especially fault diagnosing) and planning. Fault managing is concerned with solving problems in actual failure situations, thereby using and updating certain rules with the objective of returning to a good state of the overall system; see also Rasmussen and Rouse (1981) and Johannsen (1981). Planning is concerned with solving possible future problems in the sense of mentally generating a sequence of appropriate alternatives or rules for reaching future states under different foreseeable and unforeseeable conditions; see also Johannsen and Rouse (1982). In all these problem solving tasks, the rules are stored in the knowledge base after their generation or modification. From there, they can be utilized in the lower-level process of controlling (see Fig. 3).

All other tasks in man-machine systems such as, e.g., monitoring and communicating, can be classified as subtasks or supporting tasks of controlling and problem solving. Communicating comprises two very different types of communication between the members of the group jointly responsible within a

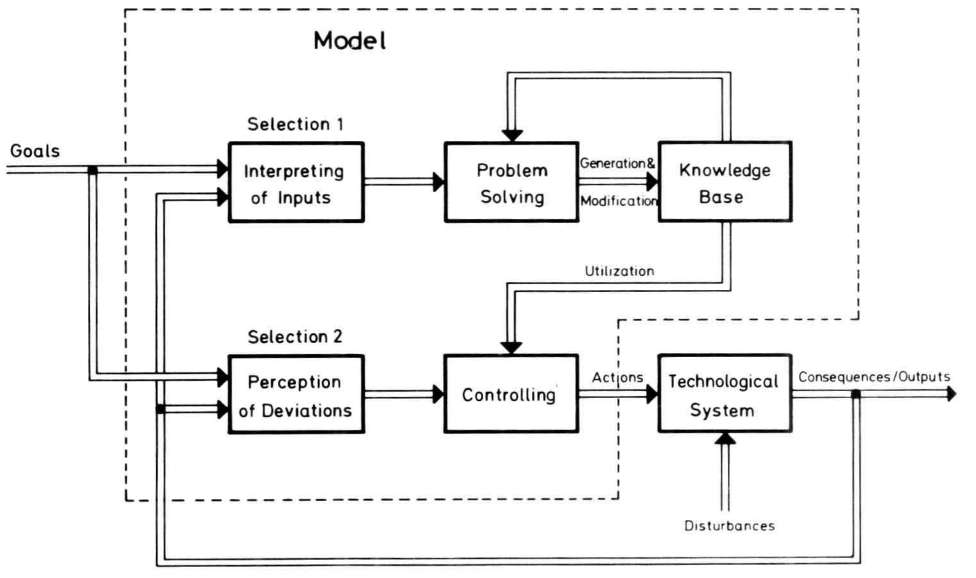

Fig. 3. Controlling and Problem Solving

man-machine system. The second type is the communication of the man with the technological system and the environment, sometimes identical with the human-computer dialog. It includes sensing, perceiving, and interpreting of input information and has been considered by Selection 1 and Selection 2 in Fig. 3. The man selects only those inputs from the generally available information source which he wants to use. This selection is handled differently for the purpose of problem solving where inputs are interpreted, and the purpose of controlling where, at a much higher pace, deviations are perceived.

Many of the topics mentioned in this introduction will be further elaborated in the survey papers and throughout the seven topic areas of this conference.

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SESSION 6 - HUMAN RELIABILITY

SESSION 7 - TRANSPORT

PERSPECTIVES ON HUMAN PERFORMANCE MODELLING

R. W. Pew and S. Baron

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INTRODUCTION

The importance of including consideration of the contribution of human performance to overall success of a complex man-machine system during the design stage is receiving wider recognition in recent years. There are differing views about how this best can be accomplished, but we consider it as an iterative process encompassing four kinds of activities; (1) Task Analysis, (2) Modelling and Prediction, (3) Simulation and Test, and (4) Functional Specification.

Task Analysis produces an in-depth statement of how the activities are accomplished in the current system in a way that focuses on the human operator's tasks. It involves the examination of written procedures, collection of interviews, direct observation and protocol data from individuals experienced in the tasks. The product is a set of flow charts and supporting material that documents the behavioral features of the task.

Modelling builds from the task-analytic output to produce a formal, often quantitative, description of the behavior of one or more people in interaction with equipment. A model of human performance requires first a model or representation of the system and environment with which the people are to function.

Simulation involves building up preprototype versions of promising system concepts, formulating specific scenarios in which they would be applicable, and testing human operators directly with the opportunity to measure their performance and to interact with the test subjects to understand the conceptual basis for their performance.

Functional Specification is the process of distilling out of the other three steps those system requirements that are essential to meet the predefined system goals and, at the same time, are responsive to the human-performance capacities and limitations that are uncovered.

The iterative and synergistic nature of these activities must be emphasized. While modelling assists in the definition of what concepts to test and what parameter boundaries are critical, testing provides empirical validation for the models as well as the basis for improving their scope and validity. The statement of functional specification delimits the range of conditions of interest and requires modelling and empirical validation as well. Modelling and testing also provide a much expanded understanding of the task that is being performed and can contribute to improved task analysis and specification for purposes of personnel selection, job design and training development.

Without intending to minimize the importance of the other activities, this paper will focus on the subject of human performance modelling:

Why do it?

What are the current methodologies?

A tempting synthesis

Behavioral and engineering scientists have differing definitions of the term model. To an engineer, a model is an abstraction that involves an explicit mathematical or computer-based formalism. The psychologist or social scientist often speaks of verbal-analytical models and uses the term in a way that is virtually synonymous with the term, theory. While subtle distinctions may be derived, we adopt the position that there is no useful distinction between models and theories. We assert that there is a continuum along which models vary that has loose verbal analogy and metaphor at one end and closed-form mathematical equations at the other, and that most models lie somewhere in-between.

We also believe that to ask whether a model is right or wrong is not the proper question. The purpose for testing the validity of a model is to decide how and under what conditions it is useful and whether its usefulness can be improved, not whether it is correct. Models are generally not disproved. They are only shown to be of restricted utility and then ultimately extended, abandoned or replaced.