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Progress Report 1 January – 31 December 1989 Information Systems Group

Edited by Leif Løvborg

Risø National Laboratory, DK-4000 Roskilde, Denmark
April 1990

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PROGRESS REPORT
1 January - 31 December 1989
INFORMATION SYSTEMS GROUP

Edited by Leif Løvborg

Abstract: The report describes the work of the Information Systems Group at Risø National Laboratory during 1989. The activities may be classified as research into human work and cognition, decision support systems, and process control and process simulation. The report includes a list of staff members.

Risø National Laboratory, DK-4000 Roskilde, Denmark
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PREFACE

This progress report summarizes work carried out in 1989 by the Information Systems Group which was a research unit based in the previous Department of Information Technology. The unit was formed in 1987 as an attempt to amalgamate two traditional Risø research topics: Cognitive man-machine studies and process simulation. The fusion came about through a common interest in knowledge-based information systems for process control and design of human-computer interfaces. In January 1990 the unit's activity and plans for the future were evaluated by an external panel of reviewers. The panel expressed the opinion that the research effort should be more strongly confined to the aspects of human cognition in connection with the introduction of advanced information technologies. A new Cognitive Systems Group became established in February 1990 as a unit belonging to the Systems Analysis Department. Some of the previous work done on the design of decision support systems was transferred to the Risk Analysis Group of the Systems Analysis Department, while the further development of inductive expert systems based on artificial neural networks was placed in Risø's new Optics and Fluid Dynamics Department. Process control and process simulation were terminated as separate Risø research topics. These changes illustrate how fast the content and organisation of goal-directed research may change in accordance with the technological evolution.

INTRODUCTION

The scientific work described here is reported under three main headings: (1) Human Work and Cognition, (2) Decision Support Systems, and (3) Process Control and Process Simulation.

The research done under the heading 'Human Work and Cognition' is concerned with the impact of modern information technology on people's work. Computers do not only change the way tasks are performed in offices and factories, they also put new cognitive demands on the users by engaging them in diagnostic reasoning and decision making related to the goals pursued by the company and to the constraints imposed on its activity by market conditions and other external factors. With a view to developing a theoretical framework that may serve as a guide to the design of user-oriented information systems, data on prototypical decision situations in various organisations are compiled through field studies and combined with the results of laboratory experiments on human learning and problem solving. This work is directed by Professor Jens Rasmussen who started Risø's man-machine studies almost three decades ago and now has an outstanding international position in this area. Since September 1989 the efforts in the area are centered around a European ESPRIT-II Basic Research Actions project called MOHAWC, which stands for 'Models of Human Actions in Work Context', and whose coordinating contractor is Professor Rasmussen. Risø's partners in the MOHAWC project include five European universities with research competence in work analysis and cognitive science, plus the Centre National de la Recherche Scientifique which sponsors a large French research program in the human factors area. A corrsponding group at JRC Ispra contributes to MOHAWC as an associated partner.

The diversified work reported under the heading 'Decision Support Systems' comprises four single projects related to, respectively, emergency management, maintenance planning, chemical process technology, and civil administration. The first and largest of these projects is entitled 'Information Technology for Emergency Management' (ISEM) and carried out under the European main ESPRIT-II program with Risø as the prime contractor.

The developments described in the category 'Process Control and Process Simulation' include a knowledge-based control system for district heating systems, a simulation model of a circulating fluid-bed furnace, and a training simulator for operators of waste burners at a garbage-processing plant.

HUMAN WORK AND COGNITION

Information technology is presently changing human work conditions in several respects. The level of mechanization and automation is steadily increasing, computers are used for planning and control of integrated manufacturing systems, computer-based interfaces are inserted between people and their work, and advanced communication networks serve to integrate the operation of large-scale, distributed systems. In this situation it is more important than ever to increase our understanding of the way the human mind works when it interacts with a socio-technical system whose information content is dispersed among computers and the brains of other people. Researchers within the discipline called cognitive science, founded some three decades ago, study human perception, memory, reasoning, decision-making, and motor skills with a view to explaining human behaviour in particular situations, related, typically, to artificial microworlds such as games. However, to predict the impact of technological changes on human performance in the complex decision situations people are faced with in modern work settings, it is necessary to study the cognitive aspects of human work in a broader context that includes the more or less concealed goals and constraints present in the work environment.

Theoretical framework for cognitive work analysis

The work operations performed collectively by the staff members of a company or organisation are manifestations of dynamic processes in a goal-directed, self-organising system that constantly must adapt itself to new conditions in accordance with the technological and social developments in the surrounding society. New technology and new work-related values and norms involve new ways of doing things without necessarily influencing the basic goals of the enterprise or changing the constraints imposed on its activity by market relations and legislation. Therefore, any attempt to predict the consequences of major technological or organisational changes must begin with a comprehensive analysis of the goals and constraints which implicitly govern the doings of the employees in an organisation.

This viewpoint is different from that prevailing in classical work psychology in which human tasks are the basic entities of description. However, tasks as perceived by an observer of human work activity are domain-specific, sequential actions that reflect a practice determined by company traditions and by individual preferences and habits. Describing and classifying work from direct field observations of people's behaviour cannot, therefore, be immediately used to predict the outcome of handling affairs and things in a different way. Our notion of a task is that of a prototypical decision situation expressed in terms of the system's means-ends structure as it manifests itself in the particular situation. In the next subsection we present an example that shows the content of a prototypical decision situation in a hospital, namely scheduling of surgery.

Where and how, then, does cognition come into the picture? Once a task has been defined in domain-relevant control and decision terms, it is possible to map the action alternatives of the human agent by considering the evidence cognitive science has to offer in regard to the ways people diagnose and interpret situations, formulate plans of action, and perform acts in the physical world. It is here an underlying assumption that human behaviour in general is characterized by lawful features that make it possible to translate a decision situation into a set of possible cognitive reaction patterns. One such feature is the information-seeking nature of the human mind. Another feature is a prounced ability of the mind to process perceived information within a subconsciously apprehended context, which enables a person to take proper action without having to reflect over all of the information available to him in the environment. A useful means of displaying an agent's actual possibilities for making mental shortcuts is to represent the cognitive task by a so-called decison ladder.

The action alternatives embedded in a task may eventually be categorized into higher-level mental strategies which <u>can</u> be used to perform the task. The freedom of action left at this stage of the analysis is what remains after all constraints related to the work domain on the one hand and to human cognitive performance on the other have been taken into consideration. To proceed further, for example with a view to simulating the effect of equipping people in an organisation with new computer tools, one will need a complete description of their individual competence, cognitive styles, and psychological characteristics. The basic idea of predicting a behavioural trajectory by removing action alternatives is illustrated in Figure 1.

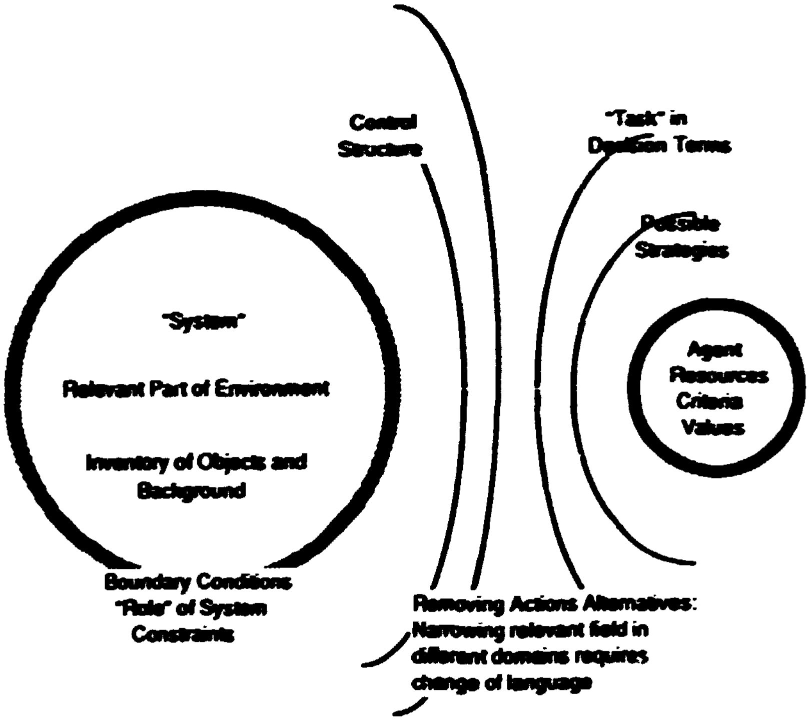

Fig. 1. The action taken by a human agent performing a task may be predicted by considering the behavioural constraints imposed by the work domain, the basic features of human cognition, and the agent's personal resources and preferences.

Field studies in a hospital

The project which is summarized in this subsection is sponsored by the State Council for Research on Technology and Science. It represents an application of the cognitive method of work analysis outlined in the preceeding subsection. The aim of the project is to develop guidelines for information systems in hospitals with special reference to the decision situation around scheduling of patient operations. The data required for the analysis were gathered from many interviews with doctors and nurses at the central hospital in Vejle, Jutland. The field work included observations of the work done in some of the hospital's treatment facilities and attending staff meetings.

The prototypcial decision situations in a hospital can be divided into several categories. Some are directly related to the patients, others are associated with administration and planning. The information flow in a hospital is, therefore, not specifically tied up with the flow of patients through the system. A large effort is done to make sure that each patient undergoes the most appropriate and cost-effective treatment at the least possible inconvenience to the patient. Meetings attended by doctors and nurses serve as a principal means to obtain consensus about what to do next with a patient. This collective decision making is largely based on information and knowledge that cannot be read in any written record, but exists in the minds of the professional people involved. Therefore, it is not obvious how some of most crucial functions in a hospital can be supported by computer systems.

Figure 2 is a graphical representation of the decision task consisting in scheduling patients for surgery. This task is performed at a weekly meeting whose central persons are the chief surgeon and the head nurse. The latter person is responsible for producing a draft plan of the operations to be performed during the following week. However, it is frequently necessary to revise this plan due to emergencies or other unforeseen factors. To make the final scheduling is what the meeting is about. The figure illustrates how a subset of the actual work-space, represented by a horizontal part-whole dimension and a vertical means-ends relation, becomes active in a specific decision situation. Such a description immediately enables the work analyst to detect the prototypical features of a task, regardless of the way the task actually is performed.

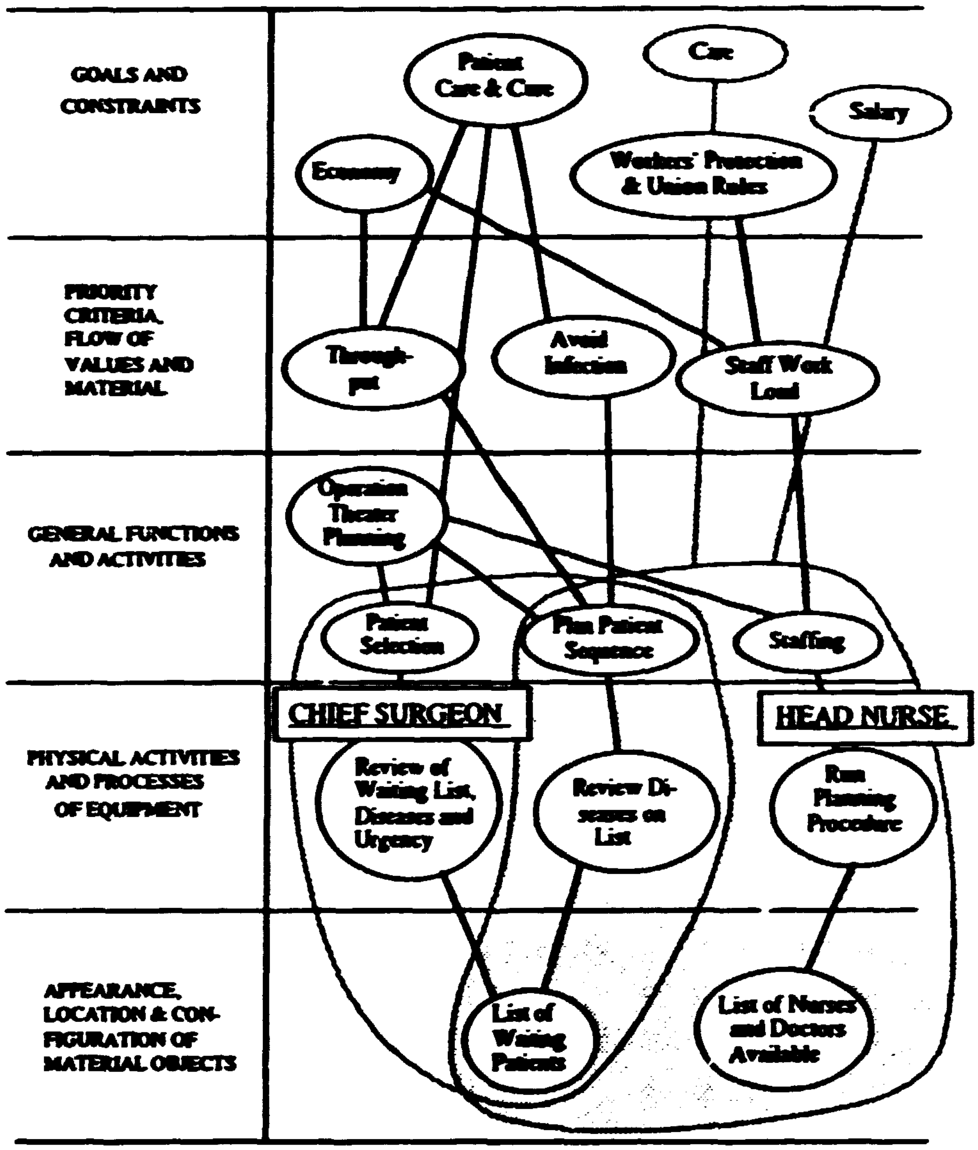

Fig. 2. Scheduling of surgery is an example of a prototypical, collective decision task in a hospital. The figure provides an overview of who is involved in the decision making and highlights the relevant items considered in the decision process. Implicit goals and constraints underlying the decisions are also represented.

Experiments on skill acquisition

Insight into the ways human beings acquire skill and exploit their skill in performing a task is of enormous importance for understanding the full implications of interposing computers between people and their work. One way of performing a skill-learning experiment is to have human subjects playing a game with a computer. By letting the computer record all of a subject's responses to the various decision problems involved in the game, the experimenter obtains an objective record of the skill acquisition in terms of, for example, score versus trial number. The annual progress report for the year 1988 contained a brief description of a fire fighting game and its application for learning studies. The problem with this and other complex games that have been developed specifically for experimental purposes is that the subjects must digest a rather extensive instruction before they can start playing the game. One cannot easily ascertain that this 'cover story' is perceived identically by different subjects.

We therefore looked into the idea of using one of the many professional video games marketed by the home computer business. These games, typically designed for the Commodore-64, are based on vivid screen animations and can be played without much prior instruction because they appeal to basic human instincts such as curiosity to explore and striving for excellence. To test this idea, we procured a game called 'Gymnastics', added code to it for recording joystick moves and associated scoring, and performed a structured experiment in which twenty-three teenagers played the game four hundred times each.

The possibility offered by this game to study learning of fast time sequences is not the most interesting aspect of the game. Since the early days of experimental psychology, much information has been provided on human reaction times and their significance for ergonomic design of tasks. As has become evident from the experiment with the twenty-three teenagers, it is much more interesting that the kind of video game selected by us can be used to highlight two factors that are of fundamental importance when a task is learned and practised: (1) people's understanding of domain-related constraints which limit their freedom of action, and (2) their self-awareness of constraints imposed by their present skill level, i.e., metacognitive control.

In the task of playing 'Gymnastics', for example, we can measure whether the subjects learn that it is impossible to land the gymnast upright if one lets her perform somersaults without sufficient jumping power. Another domain-related constraint to be learned is that somersaults must be attempted for very powerful offsets from springboard and horse; otherwise the gymnast will 'crash land'. Since both the joystick moves and the resulting scoring are logged automatically, we can easily detect when and how a subject violates these game rules. Furthermore, by training the subjects in jumping of increasing difficulty and measuring their skill towards the end of the training period, we can relate this objective information to the behaviour shown by the subjects in a game session in which they are allowed to play in accordance with their own preferences (the teenager experiment included four training sessions plus a free exercise). This is a possible way of exploring people's different conceptions of the difficulty associated with a task to which they must adapt.

Eye-mark recorder for testing of interfaces

The experimental research into cognition reported in this subsection is of high relevance to the design of computer interfaces. By recording a computer user's eye movements, problematic display elements in the screen picture may be revealed through unnecessary fixations or random scan paths. Furthermore, visual strategies may be identified as indicators of the user's search clues and patterns of information sampling, which is of great importance for iterative design improvement of 'glance guides'. The eye-mark recording system used by us is shown in Figure 3 where the equipment is being used to record the eye movements of a subject who plays the video game mentioned in the preceeding subsection.

Fig. 3. Automatic recording of eye movements in an experimental session with the 'Gymnastics' video game.

The recording system consists of a pair of goggles with a video camera attached to the forehead. Two near-infrared light-emission diodes send light into the subject's eyes. The light is reflected in the cornea and picked up by adjustable mirrors in two small cameras fitted onto each side of the pair of goggles. The mirrors are adjusted by a calibration so that the reflection point corresponds to the subject's fixation points in his visual field. In this way the fixation points and the movement patterns of each eye are registered and copied together in an external picture-processing unit and superimposed on the video picture of the central visual stimulus field taken by the forehead camera. The video recording includes digital logging of all of the fixation coordinates. The coordinates can be read by a special computer system, and software for automatic recognition of movement patterns and illustration of the fixation distribution has been developed.

Since the eye-mark recorder is portable, it can be used in external control rooms, simulators, cars, airplanes, etc. However, much of the research done or planned is concerned with interfaces on monitors. To get as big a spatial separation of the informative details as possible, we use a 37 inch monitor as presentation medium. When a subject is placed close to this monitor, he is forced to move his eyes around for long distances. This enables us to distinguish between informative parts of the picture that are placed close to each other.

One of our current laboratory applications is to record the development of orientation strategies as part of a learning process. Often an expert can pick up vast amounts of information within fringe consciousness spending a few fixations on the really important details. Knowledge about how this skill is acquired gives an increased understanding of the nature of human adaptability to technical systems. Eye-mark recordings may also be used in connection with knowledge elicitation. There may be essential expertise connected with knowing 'what to look for', e.g. when doctors are scanning X-ray pictures. Elicitation of this kind of knowledge is important when the knowledge is to be modelled in expert systems, but it is very difficult to access and verbalise the knowledge because visual orientation is so quick and smooth. This makes eye-mark recording a very strong tool: Now the expert can see a slow-motion recording of his eye movements after a well done job, and he can then try to explain the rationale of his visual orientations.

Empirical eye-mark investigations of experts performing visual judgements, e.g. quality controllers, might also turn out to be very useful for the optimisation of computer vision systems based on pattern recognition. The system can be optimised by giving high priority to the areas on which the expert tends to look fixedly when as he has tuned in on the crucial visual cues known to him from experience.

DECISION SUPPORT SYSTEMS

IT support for emergency management - ISEM

The ISEM project is a joint European project, approved and financially supported by the Commission of the European Communities, in the framework of ESPRIT-II. The consortium for the project includes seven European countries.

The potential risk of critical situations at hazardous industrial plants, still increasing in size and complexity, has drawn increased attention to emergency organisations coping with such situations. Experience gained from previous incidents and from emergency drills has revealed the complexity that must be faced in making these organisations work properly. A well-functioning preparedness system puts heavy demands on communication, accessibility of knowledge, conditions of competence, and decision making.

In order to develop a general, integrated decision support system using modern information technology for support of emergency management, there is an interest in identifying common characteristics of emergencies in various applications. The following list attempts at summarising some of the similarities.

- The systems are complex.
- There are several different organisations involved.
- Managing the emergencies requires efficient communication.
- The emergencies evolve in real-time.

Therefore it seems - and will be further investigated in this project - that similarities may be found even in emergency situations that originally are of quite different nature.

For all emergency management systems user requirements may be specified in a common way. The system shall:

- collect the measurement data that are needed and useful,
- keep records of the present state of the system,
- give useful information about the current state and about the level of service offered by the system,
- keep a record of the recent action that might not yet have visible effects due to delays in the processes being observed,
- reach the right organisations in the intended order,
- produce guidance for the operator and the decision-maker,
- help to co-ordinate actions,
- monitor the plans and actions to determine how well actions follow the plans,
- provide support for reaching consistency of decisions,
- adapt dynamically to the current situation,
- remind the operator periodically to check the situation and trends at critical parts,
- provide support of the coordination of activities among decision makers
- include preparedness plans,
- include access to customer's existing data bases or other relevant data bases available.

Aiming at this, the main features to be developed will be an Application Generator presenting a set of more or less fixed procedures and software tools for generating a distributed decision support system as an ISEM end product. Within the Application Generator an organisational model and an information flow model are the basis for the construction of the support system. A model of the Application Generator is shown in Figure 4.

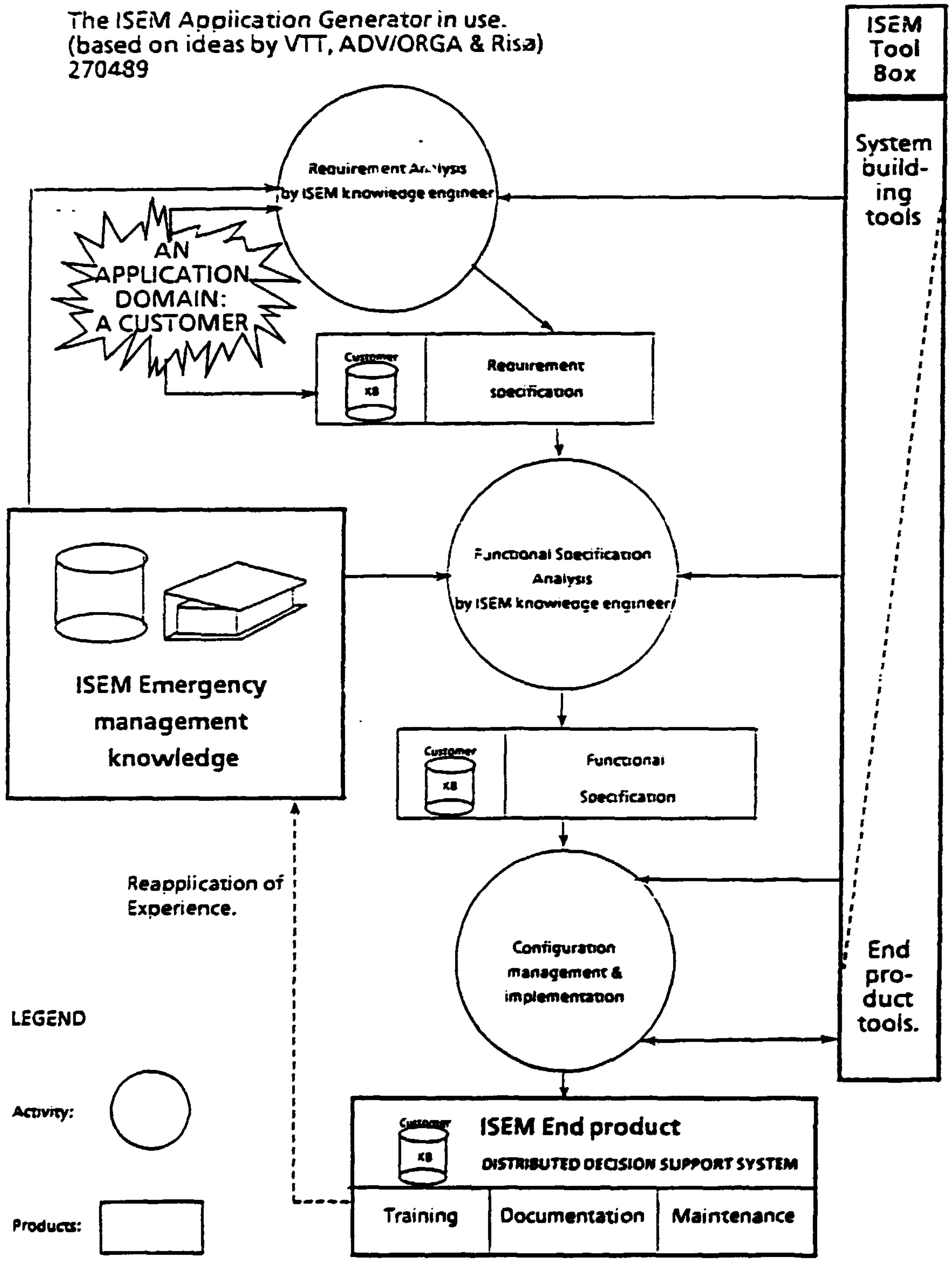

Figure 4. Schematic representation of the Application Generator to be developed under the ISEM project.

Decision support for maintenance planning

In collaboration with the Risk Analysis Group of the Systems Ananlysis Department a project concerning maintenance planning in industrial plants is being carried out. The project is partly supported by the Nordic Industrial Foundation and the State Council for Research on Technology and Science.

The main ideas behind the project are to base the maintenance planning on the current reliability state of the plant and its components and to use information technnlogy to set up a decision support system for the maintenance planners. Furthermore, a differentiated man-machine interface is going to supply other members of the organizational hierarchy, such as managers, operational staff, and maintenance workers, with information and advice suited for their specific needs.

Important elements of the system are:

- Measurement and use of parameters influencing component and plant reliability, e.g. vibrations, wear, excessive temperatures or pressures.
- The use of a reliability model of the plant for on-line calculation of the current reliability status with the most recent data for component reliability.
- A 'dynamic history data base' (DHDB) containing all information about the maintenance and operational history of the plant. The data are used as input for the reliability model, either directly or after preprocessing in statistical modules.
- A user-friendly man-machine interface which provides the information needed by different groups of personnel, e.g. maintenance planning advice for the people responsible in that field, spare parts information for the crew performing maintenance, and figures for the managers on the longer term availability of the plant. The interface for each category is to be adapted to the specific needs and language of the people concerned. This means that the interfaces must be

designed in close collaboration with the staff. Furthermore, the organizational structure must be examined in order to identify what people needs which information as decision support.

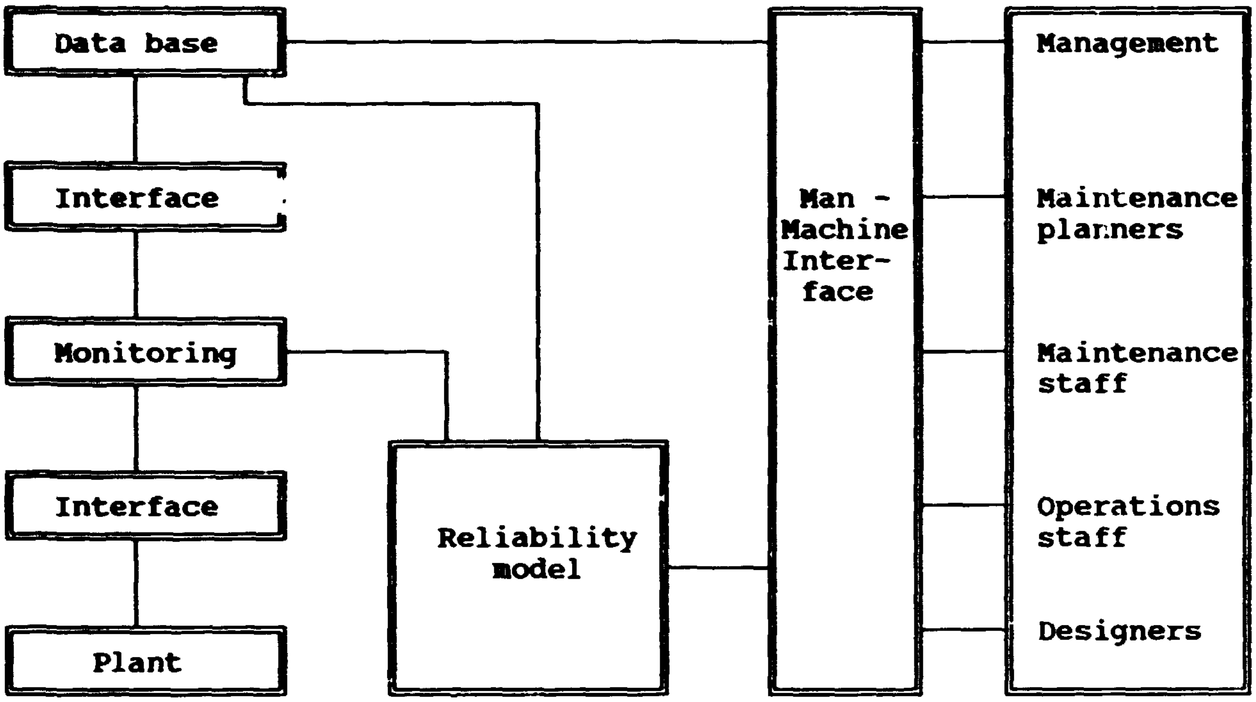

Fig. 5. Essential components of an information system for maintenance planning.

Interface system for pipe-autoclave installation

Prompted by ongoing experiments with de-toxification of polluted soil by wet-air oxidation in a large pipe-autoclave installation at Risø, a computer-based data-acquisition and process-display system has been developed. The system provides the process operator as well as the process engineer with suitable displays of critical parameters in the autoclaving process. For the operator the critical problem in running the process is the formation of crusts on the inner surface of the pipes. These crusts produce an increased pressure drop along the pipes so that the water inside the autoclave may start boiling. It is therefore particularly relevant to monitor and display the pressure drops at selected points in the process system.

The information system developed can be used as an on-line decision support system or it can replay and display old process data stored on disk files. Future developments of the system will include the calculation and display of heat formation from exothermic processes, and estimating the current thicknesses of crusts to indicate at what time it will be necessary to invoke a crust-removal procedure.

Expert systems using artificial neural networks

One of the most important features which distinguishes neural networks from other expert-system development tools is their ability to generalise. This means that a neural network can produce meaningful answers to questions it never was taught to answer as long as the questions are not too different from the ones it has been taught. The expert-system shell briefly described here utilizes artificial neural networks as the 'knowledge engine' and minimal entropy coding as the main support technique for knowledge acquisition. Minimal entropy coding is a method based on information theory for minimising the description space of a problem domain. The shell has been used to build two expert systems in the area of legal decision support, one for the police and the other for the customs authorities. Both systems cover medium-sized expert domains and were built with an effort of three to four man-weeks only. This speed of development would not have been possible if a rule-based expert-system shell had been used. In fact, it would probably not have been impossible to build the system for the customs authority using rule-based techniques.

The knowledge-acquisition module of the shell has a user-friendly interactive example editor and full logical support for "don't care" values and conflicting examples. After a couple of days of instruction the local experts or office workers can themselves expand and finish the system and interface it to existing word processors, data bases, etc. The shell uses up-to-date menu techniques and has an always active help line which explains both the functionalities and the expert-domain items to the user. In addition to the neural network there are simple and yet powerful tools for report generation, maintenance of the knowledge base, maintenance of help texts, and further decision support in difficult cases. During normal work the user will be prompted to update the example base whenever a decision with no match in the example base occurs. The new decision will be checked for conflicts with existing examples, and advice for conflict resolution is suggested if necessary. The system asks for retraining if the example base has been changed. Thus, knowledge maintenance is done with a few key strokes during normal work.

Whenever a system is able to generalise there is a chance that it does it wrong. Research has been carried out to develop methods for measuring how well a neural network generalises from certain domains which we whished the network to learn about. A probabilistic theory based upon the Vapnik-Chervonenski dimension tells us which network architecture to use in order to ensure a certain quality of the generalisation. Another method, which is currently being developed, can classify answers from neural networks into groups of certain and uncertain answers. This is of great importance in the design of decision support systems whose uncertain answers must be identified for reliability reasons.

PROCESS CONTROL AND PROCESS SIMULATION

Knowledge-based control of district heating systems

Previously reported work on the development of a module for knowledge-based process control and diagnosis of district heating systems has been finished. The work was done in cooperation with a Danish industrial company which produces and sells such systems. The knowledge-based system consists of a central computer with software and a number of substations which take care of the detailed local control of the system. The central computer (the main station) carries out the main control and data collection in the system and is used for programming the substations. The operator of the heating system can change parameters from the main station in the substations and in that way change the behaviour of the system. He can also supervise the system from the main station. During the project a module was developed which has been integrated with the existing software for the main station. The module contains an inductive expert-system shell where knowledge about the system together with actual measurements provided by the system can be used for suggesting the operator to change the state of the system as well as for obtaining diagnosis of errors in the system.

The software developed has been successfully been tested against an existing heating system as well as a simulation model of such a system. The three main conclusions from the project are: (1) It is possible to implement knowledge-based techniques in existing software; (2) Knowledge about the domain, in this case heating systems, is important when actually trying to use a module as the one mentioned above; and (3) Such knowledge can be captured in a knowledge-based system and later be re-used by less experienced operators.

Simulation model of circulating fluid-bed furnace

A simulation model of a circulating fluid-bed furnace (CFB furnace) has been developed for the Swedish power-supply enterprise 'Sydkraft' in Sweden. The model development started at Risø using DYSIM, a modular simulation system (MMS) for continuous processes which has been created and commercialised at Risø. The model was next translated into the simulation language ACSL, Advanced Continuous Simulation Language, which is the underlying language for MMS models. The ACSL model conforming to the MMS requirements was finally installed for 'Sydkraft in the EASE+ graphic interface for MMS.

A schematic diagram of the CFB furnace system is shown in Figure 6. The CFB model includes the steam production provided by the furnace, a steam drum, and a steam superheater. The CFB unit itself consists of a reactor where the combustion takes place and four cyclones where gas and bed material are separated.

MMS is a simulation system with modular modelling components used in the nuclear and traditional power production industry. Risø was asked to make the CFB model because this is an example of a non-existing component in MMS. It is possible to extend MMS with new modules but it must be done by carefully following the directions of MMS. This includes extended documentation for model development, model description including a complete list of variables, their meaning and parameters, how to extract values from data, tests of model, source code, etc. This secures the potential for usage by other model developers.

The code produced by translating the DYSIM model into ACSL was installed in the MMS system without problems, and the tests run in DYSIM were reproduced in ACSL and MMS. Some time was spent on installing the CFB module in the graphic interface MMS/EASE+. The MMS/EASE+ system facilitates the development of MMS models when modules are found in the MMS component library. It was not straightforward to add new components to the system, but when it

has been done (in the proper MMS fashion), great potentials for re-use exist.

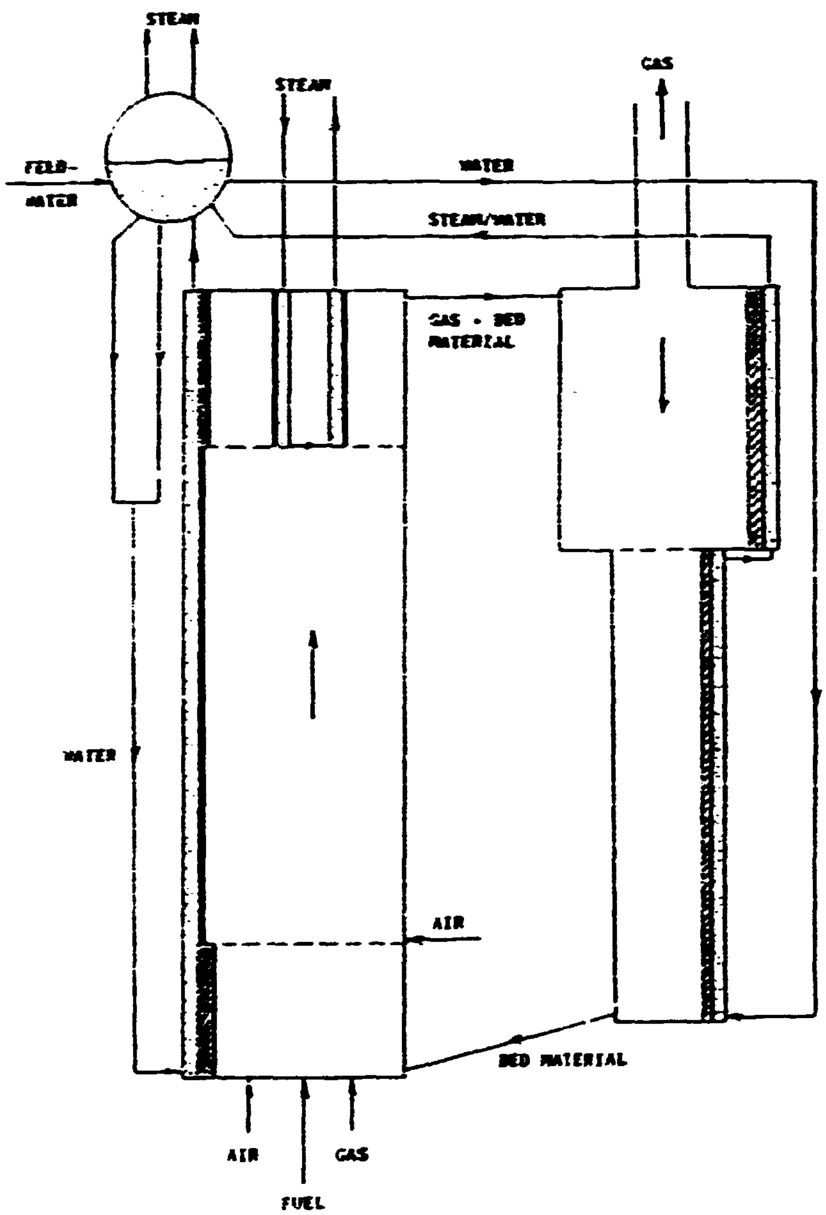

Fig. 6. Schematic diagram of circulating fluid-bed furnace.

Training simulator for operators of waste burners

The simulator briefly described here was developed in cooperation with a Danish company specializing in garbage burning. It was installed for training of operators of industrial waste burners at a labour-union educational centre in Jutland. The simulator consists of a dynamical plant model and includes a graphic user interface. The plant model has four modules: One for manipulating three kinds of garbage and feeding the furnace, a second for simulation of the reaction processes and the heat transfer in the furnace, a third for simulating the reactions in a secondary, CO-reducing chamber, and a fourth for simulation of a vessel which transfers heat from the hot gas to water used for district heating.

The graphic interface of the simulator displays a main picture that provides the values of major process variables as columns with indication of alarm status. The main picture also gives an overview of the components of the plant (Figure 7). Control of the simulated plant, i.e. feeding the furnace, manipulating the grate speed, opening air valves, and operating an air preheater, is performed with a mouse. The trainee has an option to call up extra information in a small window, or to display trend curves as a substitute for the main picture. Furthermore, he may suspend the simulation or stop it at any time.

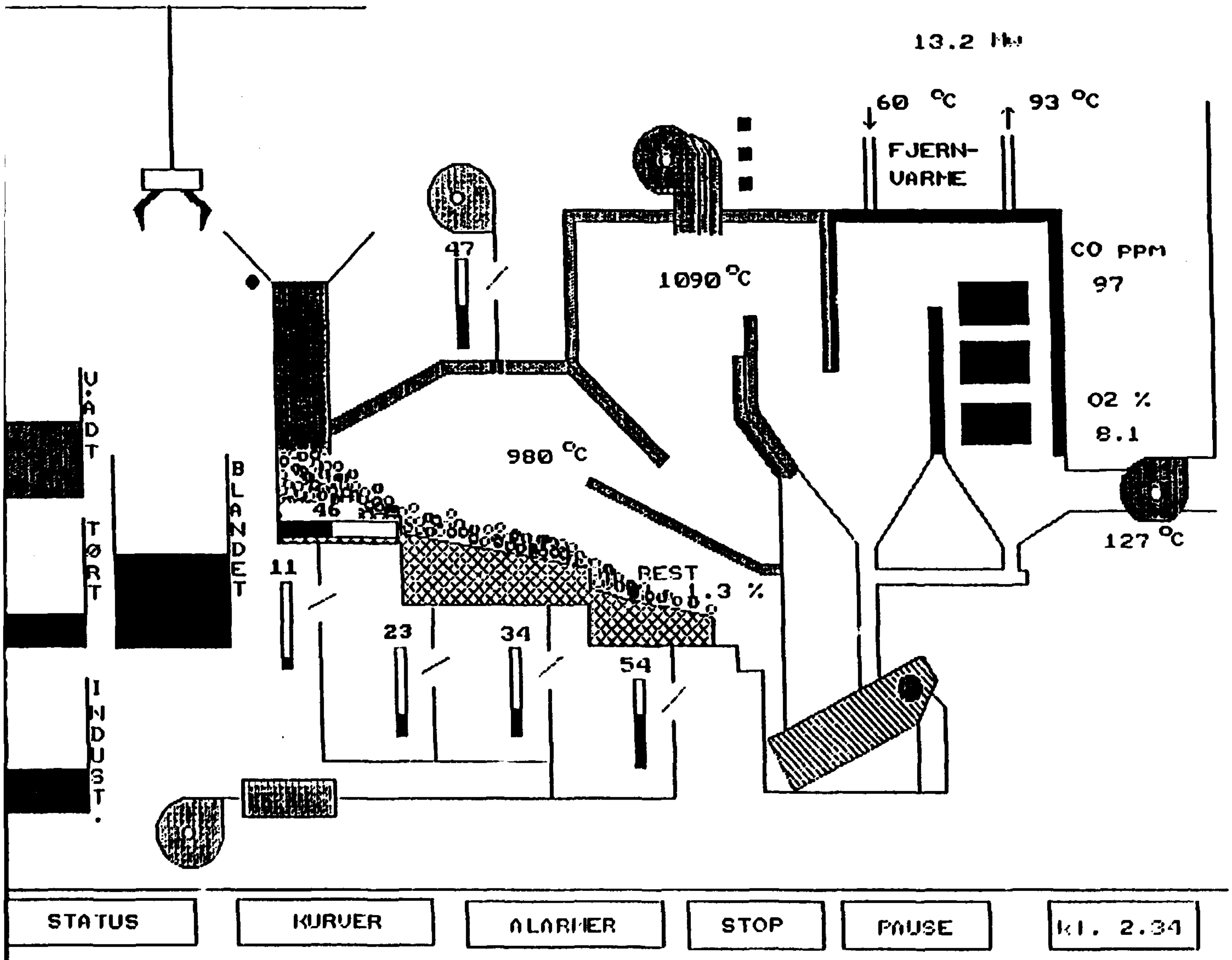

Fig. 7. Screen picture of training simulator for garbage-burning plant.

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The report describes the work of the Information Systems Group at Risø National Laboratory during 1989. The activities may be classified as research into human work and cognition, decision support systems, and process control and process simulation. The report includes a list of staff members.

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