ISACS-1, A LIMITED PROTOTYPE OF AN ADVANCED CONTROL ROOM

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ABSTRACT

The concept of an Integrated Surveillance And Control System (ISACS) has been developed into a prototype, ISACS-1, which presently is in operation at the simulator-based experimental control room HAMMLAB of the OECD Halden Reactor Project. Characteristics of ISACS is that it covers the whole interface between the process and the operator, and this interface is fully computerised using tools like Cathode Ray Tubes (CRTs) and dynamic keyboards. In addition, a large number of computerised operator support systems (COSSs) are included in ISACS, assisting the operator in functions like disturbance detection and diagnosis, identification of relevant actions, and implementation of procedures. An information coordinator called "Intelligent Coordinator" (IC) in ISACS observes the information received from the process and the COSSs, generates new high-level information and structures and prioritises information to be presented to the operator.

The limited ISACS-1 prototype was completed in early 1991. An extensive evaluation programme is in progress. This paper will describe main features of the system and some of the conclusions to be drawn frm the evaluation programme.

1. THE NEED FOR AN INTEGRATED APPROACH IN CONTROL ROOM DESIGN

Even if nuclear power generating plants have a very good safety record, there is a strong motivation in all countries for further improvements. Control room improvement is given high priority, and modern computer technology, used in the correct manner, has the potential of greatly improving operational safety.

A number of weaknesses in old control rooms have been identified: Relevant information may be missing due to limited instrumentation, too much information (alarms) may make it difficult for the operator to diagnose the process state, wrong or inconsistent information may mislead the operator. In addition, the operator could benefit from assistance in both diagnosis of problems, in action planning and in implementation of control actions.

Techniques are available to improve on all the points given above: Dynamic process models may supply relevant process information, alarms may be filtered and presented more clearly and well structured, consistency check of process data before presentation helps identify wrong measurements. Knowledge-based or model-based operator support systems may suggest diagnosis and which procedures are relevant. Finally, computerised procedures may prevent the introduction of errors that often are experienced.

Efficient operator support in these tasks puts strict requirements to the integration of the various computerised operator support systems (COSSs). Adding new COSSs adds more information in the control room, increasing the danger of information overflow. The Man-Machine Interfaces (MMI) of the COSSs must be standardised. One must avoid that the operator is so involved in the use of a COSS that he overlooks more important tasks to be performed. Also, implementing a large number of

COSSs that are not coordinated with respect to process coupling and computer application is ineffective and expensive.

A set of requirements to the advanced control room follows from this: The integrated concept must cover the complete MMI, and the MMI of the COSSs must function as a unified interface. A computerised "intelligent coordinator" must keep an overview of the process and COSS information as a basis for analysing plant conditions and prioritising information. At the same time, the operator must have the freedom to request any information available, to maintain his role as responsible for control of the process. These requirements have been important when the concept for the integrated surveillance and control system ISACS was defined.

Introduction of a concept like ISACS creates a completely new working environment for the operator characterised by the availability of more and different types of information than in todays control rooms. This affects the role of the operator. Care should be taken that the correct balance between technology and the human being is obtained, avoiding a situation where the technology takes over tasks that are better performed by the operator.

2. THE ISACS-1 PROTOTYPE

Early in the development process it became clear that it would be impossible to specify a fully functional ISACS without first gaining experience with a limited prototype. Thus, functional requirements and specifications for a limited prototype called ISACS-1 were developed in 1989. During 1990, ISACS-1 was implemented and integrated, and the system became fully operational in 1991, coupled to the full-scope Pressurized Water Reactor (PWR) simulator (1, 2).

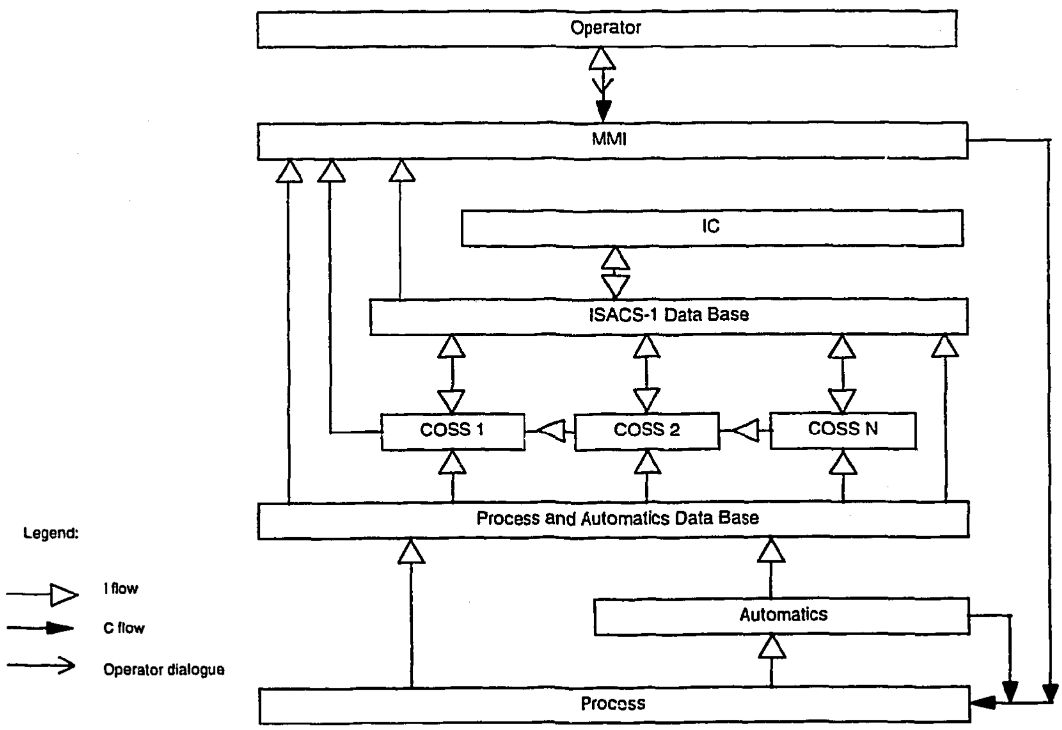

Figure 1. *ISACS-1 main system structure*

The main system structure of ISACS-1 is shown in Figure 1. The (hard) automatic circuits receive information (I) from the process instrumentation, and based on the inherent logics, automatic process control is executed via the actuators. The data from the process and the automatics are continuously stored in the Process and Automatics (P&A) data base. In principle, all these data are available to the operator via the dialogue capabilities fo the Man-Machine Interface (MMI). The MMI includes all information presentation and all manual plant control actions.

The ISACS-1 data base contains a minimum amount of data, i.e. the necessary data which the Intelligent Coordinator (IC) needs for the reasoning, and the data which each COSS needs from the IC and the other COSSs. The COSSs extract the specific data they need from the P&A data base and from the ISACS-1 data base, and store in the latter the data needed by the IC and the other COSSs. In addition, the data from each COSS is directly available to the oepator through the MMI dialogue (display retrieval, COSS control, etc.). The IC extracts all process and COSS data it needs from the ISACS-1 data base, and store all results of interest to the operator through the MMI. All communication between operator and IC is via the ISACS-1 data base. The operator executes the process controls through the MMI.

2.1 Computerised Operator Support Systems

A total of 8 different COSSs are included in the ISACS-1 setup. The selection of COSSs in ISACS-1 is based on those systems available in the Halden Man-Machine Laboratory, HAMMLAB, coupled to the PWR simulator. They all complement each other, and in sum they represent most of the classes of support systems that exist today. A main principle in ISACS, however, is that exchange of COSSs should not result in major modifications in the integrated system. The ISACS concept is therefore equally valid when coupled to a different set of COSSs, but they should serve the same type of functions.

HALO (Handling of Alarms using LOgics) filters conventional process alarms to avoid irrelevant alarms. The system also presents the alarms in an overview display, and in detailed process displays. In ISACS-1, HALO supplies the coordinator with all system/group alarms.

DISKET is an alarm diagnosis system that, based on the alarm pattern from HALO, generates hypotheses for the cause of the alarms. DISKET is a knowledge-based system where information on patterns of the actual alarms and other variables are matched with precalculated patterns from known disturbances. In ISACS-1, DISKET is activated when alarms have been detected by HALO. ISACS then compares the DISKET diagnosis with diagnosis from other systems (see below).

Early Fault Detection (EFD) is an alarm system where alarms are given if differences are detected between process measurements and output from dynamic process models. EFD acts as a complement to HALO. The available version of the system has been developed for fault detection mainly in the feedwater system of the plant.

Detailed Diagnosis (DD) has been developed to perform diagnosis of alarms originating from EFD. A first version of the system is used in ISACS-1. The diagnosis uses knowledge-based techniques. Typically the result will be identification of failed components, control system failure or instrument malfunction. ISACS-1 receives the diagnosis from DD and compares it with diagnosis from DISKET.

Detailed Prognosis (DP) predicts process behaviour following a disturbance detected by EFD and diagnosed by DD. The system is model-based. The output is useful to judge the severity of the disturbance and its expected consequences. ISACS judges the severity of the situation as basis for recommendations to the operator.

The Critical Function Monitoring System (CFMS) was developed by Combustion Engineering and is in operation in HAMMLAB as an integrated part of the Success Path Monitoring System (SPMS). it detects when a critical safety function is in jeopardy, and gives information to the operator via a set of tailormade displays. In ISACS-1, CFMS makes up a part of the alarm system.

The Success Path Monitoring (SPMS) was developed by Combustion Engineering and evaluated in HAMMLAB. The system checks the availability of a set of predefined success paths assigned to each of the critical functions. SPMS suggests available action plans to the operator when a critical function is being jeopardised.

Among the operator support systems developed at Halden, COPMA is the only system dedicated to assist in action implementation. In COPMA, operational procedures are implemented on the computer and made available to the operator as he is working through the procedure. COPMA is coupled to the process data so that process controls can be executed directly via the procedures.

2.2 The Intelligent Coordinator

The role of the coordinator (IC) in ISACS is twofold:

1. Supervise and control COSSs and process data: Continuously supervise appropriate COSS analyses for current situation, activate passive COSSs when necessary and summarise status for the operator.

2. Act on operator request: When requested by the operator, coordinate additional assessments as requested and report the results.

In the supervisory role the coordinator will prioritise and convey information from COSSs to the overview display according to plant state. The operator can extract more detailed information in second level displays which are maintained by the coordinator. Finally, the coordinator will propose detailed displays to the operator, either process pictures or special procedures designed for relevance to the current plant state.

In the second role the coordinator must interpret and convey requests to COSSs. Since there are several systems available, one must be able to switch easily between the various systems as the operator demands are changing.

2.3 Man-Machine Interface

The MMI of ISACS-1 is intended to act as a single, integrated interface for the operator in all operational modes via a set of modern workstation computers equipped with full-graphic colour CRT screens, keyboards and trackerballs, or equivalent equipment.

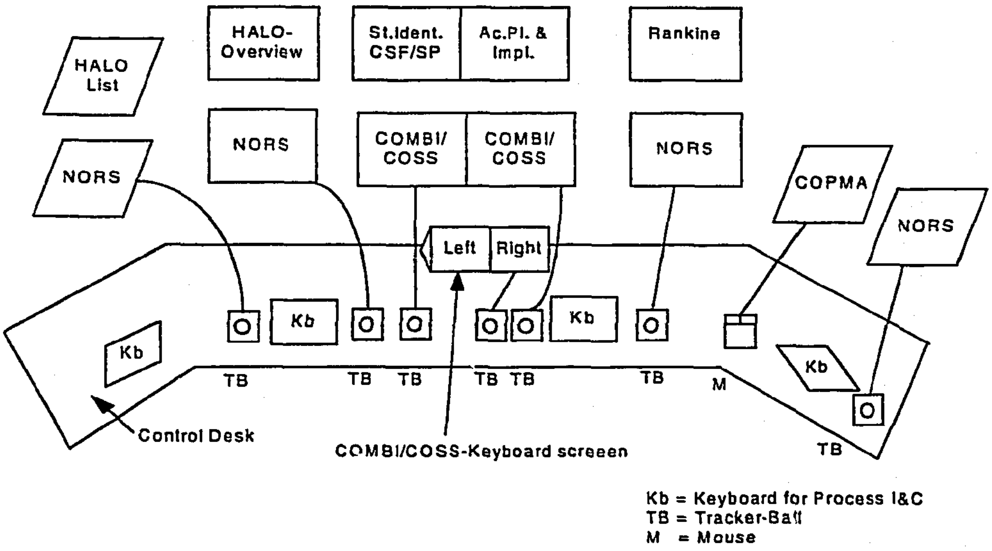

Figure 2. *ISACS-2 control station layout*

Figure 2 shows the control station layout in ISACS-1. It consists of a U-shaped control desk with two rows of CRT-screens with keyboards and trackerballs. The lower row is positioed at about the same height level as the control desk surface while the second row is placed just on top of the lower one. In total, there are 13 screens (12 colour graphic CRTs, 1 black/white), and a bell for the HALO alarm system.

The design can be characterised to be a "cockpit control room", which implies that the operators have all essential Information and Controls (I&C) available to them at their normal working position, i.e. sitting on a chair along the control desk. The control room is intended for one or two operators and one or no supervisor.

The screens in the upper row except for HALO List, present overview information from the process i.e. the full-scope PWR simulator, for the COSSs and the IC, while the lower row screens constitute the operating level displays and present more detailed information from the same sources. The operator has no control over the information presented to him in the overview displays, but he can to a large extent decide what to display on the operating level displays. No dialogue and process control actions can be executed by the operator via the overview displays, only through the operating displays and keyboards in the lower row.

The MMI of ISACS-1 consists of the following parts:

- Overview information on the four displays: HALO Overview, State Identification, Action Planning & Implementation, and Rankine.
- HALO List, alarm screen displaying the alarms as text strings.
- Four identical PWR simulator process I&C stations, for operating the plant.
- COPMA, work station for computerised procedures.
- The three stations COMBI/COSS and COMBI/COSS Keyboards, where the MMI of six different COSSs (CFMS, SPMS, DISKET, EFD, DD, DP) are integrated, (COMBI: COMBined Information).

The IC presents its results to the operator in the State Identification (SI) and Action Planning & Implementation (AP) overview displays, as well as in the COMBI displays, which are also integrated in the COMBI/COSS stations.

3. EVALUATION OF ISACS-1

The experimental control room where ISACS-1 is implemented, is equipped with video and audio recording facilities and automatic computer logging of operator and instructor/experimenter actions, process alarms and selected plant parameters. Interaction with, and output from different support systems can also be automatically logged. The simulation is based on models of the Loviisa plant in Finland. This equipment provides an excellent test bed for human-computer interaction issues.

It was decided to carry out the evaluation of ISACS on a limited first prototype. The reason for this was to get feedback at an early stage and to make modifications in the further development of the system based on the outcome of the evaluations. It is important to note that this first prototype of ISACS is not a system meant to be implemented in a control room in its current form. ISACS-1 must be considered as a "futuristic" concept representing an idea of the next generation of advanced control rooms. However, the current version of ISACS represents the concept with such a fidelity that it allows test and evaluation of its impact on human-computer interaction.

Most of the COSSs integrated in ISACS-1 have already been evaluated as single, individual systems in HAMMLAB. Typically, the experiments have been made with reactor operators as test subjects. Operator performance with and without using the COSS has been measured. In most cases, significant improvement in operator performance has been found when a COSS has been made available.

The evaluation of ISACS has followed a different approach, including several steps. In this way, various aspects of the advanced control room concept may be investigated. Today, three steps in the evaluation process have been taken. A fourth evaluation method, measurement of situation awareness, has been developed for use in the nuclear field. In the following, the purpose with and main results from these steps are described.

3.1 Guideline Evaluation

The integration of several different COSSs into an integrated system requires that the different COSS interfaces are integrated. The aim is to make the system appear as one uniform system, with a shared interface. A wide range of basic MMI topics on this level was identified, ranging from characters, colours, symbols and similar screen design items, and different user interaction methods. If the system is applying consistent policies for information presentation and information handling, this will ease the operator's interpretation and use of information. The consequence of lacking consistency would be that the operator will have to apply different interpretation strategies on different parts of the system. This will place heavy demands on operators cognitive capacity and thereby increasing the possibility for erroneous interpretations of information and erroneous actions.

A guideline review was selected as a method to address the first level of user interface aspects. The guideline review was aiming at bringing the MMI of ISACS-1 in compliance with the research recommendation and practices.

Guidelines should be used with caution, because the individual guidelines stated in different guideline collections could have a very varied empirical or practical background, and be adopted from different human computer systems. For some guidelines it was necessary to check with referenced source documents to be able to determine whether the guideline applied to our setting or not. Unfortunately, for many of the guidelines, references to source material were unobtainable. One guideline collecion was found particularly useful. (3).

Results show that there is an inconsistent use of coding remedies throughout the system. Another weakness was a too long system response time for presentation of certain types of high level information. The guideline method was relatively easy to perform. It was deemed useful to address this type of questions, and it provided concrete recommendations to further improvements of the design.

3.2 GOMS Analysis

The second evaluation phase was using the GOMS methodology (4). GOMS is an abbreviation for Goals, Operators, Methods and Selection rules. Goals are what the operator tries to accomplish. Goals are hierarchically organised. A goal may be described in terms of one or more sub goals, which must be achieved to fulfil the final goal. Operators are the actions available for the human operator to achieve a goal. Methods are the sequence of individaul operators that lead to fulfilment of a goal. Selection rules are the rules used to select between different methods available to achieve a goal.

The GOMS method describes and analyses the interaction between the human and the computer. GOMS is a formal way to express the procedural knowledge ("how to do it knowledge") an operator needs to operate a system. The GOMS formalism describes the content and the structure of this knowledge. Since GOMS is a production rule system, GOMS adopts the assumption that human actions, both manual and cognitive actions (e.g. retrieve information) are quantifiable, and that each step in a production rule corresponds to one single action.

On the basis of these assumptions one can give quantitative estimates of the time and effort required to interact with a system. This can be time to reach a goal, time to learn to use a system, bottlenecks in the interaction, degree of transfer of learning between different systems and the amount of mental workload involved in performing tasks.

The GOMS method is traditionally applied to text editors and related applications. To the authors' knowledge, this is the first time that the method is applied in process control. Results show that ISACS-1 help the operator in handling scenarios by splitting complex and ill-defined tasks into manageable sub tasks. This reduces the mental workload involved in handling scenarios. Furthermore, the analysis identified existing bottlenecks in the system, especially concerning too large demands on the operator's ability to remember information across different screens and different tasks. It was also demonstrated that there were instances of slightly different methods of achieving the same goal, introducing new tasks on the operator to identify the right method. The analysis demonstrated improved methods of interaction with the system. The results from the GOMS analysis overlap to some extent with the guideline evaluation, stressing the need for consistent use of all coding remedies.

3.3 Informal User Tests

The third step in the evaluation process invovled use of expert operators from the Loviisa plant in Finland. The NORS simulator in HAMMLAB is very similar to the Loviisa training simulator. The Loviisa operators may, therefore, be considered experts on the process.

The intention with the informal user test consisting of dynamic "walk through/talk through" exercises was to assess how well the ISACS-1 MMI covered the operators' need for information. The experiment included dynamic simulations followed by freeze of the simulator whereupon structured interviews of the operators were made.

Analysis of the test clearly demonstrated the test subject's high level of competence. The operators were able to diagnose the 6 transients in the existing ISACS scenario based on the process information presented on the NORS process displays. The guidance given by ISACS was therefore not needed. For future experiments with expert test subjects, the complexity of the scenario should be increased to construct situations where the operators would have problems understanding the disturbance and performing the correct action.

The intention with ISACS is that it should look like a single, unified system to the user. The present version was experienced as split into two, one part consisting of the NORS process displays, the second made up by the MMI giving the information from the COSSs and the Intelligent Coordinator. More emphasis should therefore be put on unifying the MMI. It should be mentioned, however, that while the operators were rather familiar with the NORS displays, they had little training in use of the higher level functions in ISACS.

ISACS is intended to act as an advisor to the operator, not a supervisor. This should be made more clear in the design of the MMI, as the operators felt uncertain about the role of ISACS.

The COMBI displays containing all essential information on an event were appreciated. This suggests that the concept of event used in ISACS, where event means a planned or unplanned transient, is useful. The COMBI information includes typically a mimic diagram of the relevant process section, trend of important variables, diagnosis of problems, and advice on actions to be taken.

The present version of ISACS presents some high level information with a considerable time delay, due to bottlenecks in the present software/hardware. This is not acceptable, and detailed system analysis and improvements are underway.

Use of expert operators from Loviisa in ISACS evaluation has proved highly beneficial, and may hopefully be extended in the future.

3.4 Situation Awareness

One of the goals of ISACS-1 is to enhance the operator's overview of the process. This is done by coordinating and prioritising information and present the operator with concise events and key process variables. We want to develop a measurement that reflects ISACS-1 impact on operators mental representation of the process status. Situation awareness was decided to serve as such a measurement.

Results from these studies are presented in a separate paper at this meeting (5). The conclusion is that measurement of situation awareness is feasible for evaluation of nuclear power plant control rooms. The method will be applied in future ISACS evaluations.

4. IMPROVEMENTS OF ISACS-1

Feedback on the quality of ISACS-1 has been obtained from formal human factors evalutions, demonstrations to a large number of external experts and accumulated experience gained by in-house staff. This knowledge is being used partly to create improved versions of ISACS-1, partly to serve as a basis for a future ISACS-2.

One important improvement of ISACS-1 is to remove bottlenecks in the computer system that resulted in unacceptable delays in information presentation. Detailed investigations were therefore initiated to localise critical points in the hardware/software system. Through hardware extensions and replacements, restructuring and modification of software, major bottlenecks have been removed.

Modification of the MMI is ongoing, presently centered around the process mimic displays. Further, a new alarm system allowing for a much more flexible handling and presentation of alarms is being introduced. These improvements will be implemented in early 1995.

On a longer time perspective, development of ISACS-2 will be initiated. Emphasis will be put on optimal distribution of tasks between operator and the computerised interface and the generation of a unified interface. Further, the question of which functions to be allocated to the control room will be analysed. Interesting issues here are the integration of operation and maintenance and possibilities for on-line assessment of overall plant safety conditions.

5. CONCLUSIONS

A first, limited prototype version of the advanced control room concept ISACS has been developed. Based on the feedback from the evaluation programme conclusion is that the concept seems to have the potential of improving operational safety and efficiency. This will be further studies in the future. Experience from continued evaluation will constitute the basis for development of a new prototype, ISACS-2. The results from the system evaluation will also be more generally applied, giving increased knowledge that can be used as a basis for formulating guidelines on design of advanced control rooms. Further, the experience gained from using a wide spectrum of evaluation techniques will contribute to the knowledge based needed to formulate guidelines for evaluation of advanced control rooms.

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