Comparison of Alarm Systems for Advanced Control Room

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ABSTRACT

This study is carried out to investigate performance differences between two alarm presentation methods from the viewpoint of human factors and to provide items to be improved. One of the alarm display methods considered in this study displays alarm lists on VDT combined with hardwired alarm panels. The other method displays alarms on plant mimic diagrams of VDT. This alarm display method has other features for operator aid with which operator can get detailed information on the activated alarm in the mimic diagrams, and the capability for alarm processing such as alarm reduction and prioritization.

To compare the two display methods, a human factor experiment was performed with a plant simulator in the ITF (Integrated Test Facility) that plant operators run for 4 event scenarios. During the experiment, physiological measurements, system and operator action log, and audio/video recordings were collected. Operators' subjective opinion was collected as well after the experiment. Time, error rate and situation awareness were major human factor criteria used for the comparison during the analysis stage of the experiment. No statistical significance was found in the results of our statistical comparison analysis. Several findings were identified, however, through the analysis of subjective opinions.

INTRODUCTION

The basic role of alarm systems in nuclear power plant (NPP) is to alert operators to plant disturbances. However, advanced alarm systems being developed in the world intend to provide operators with processed alarm information with which operators can be aware of plant status quickly and correctly. Since VDTs are considered for alarm displays, alarm reduction, prioritization and display schemes become the main issues in the development of alarm systems.

KAERI developed a prototype of an alarm system called ADIOS(Alarm and Diagnosis Integrated Operator Support), which displays alarms on plant mimic diagrams with the capabilities of state/mode-dependent processing, dark-board concept, alarm classification, and so on.

In this study, we compared the ADIOS prototype with the alarm system in the Integrated Test Facility (ITF) using a human factors experiment. In the human factor experiment, plant operators run 4 event scenarios on a plant simulator in ITF. Physiological measurements, system and operator action log, and audio/video recordings were collected. The operators' subjective opinions were collected as well after the experiment. We carried out quantitative and qualitative analysis of the collected data. Time, error rate and situation awareness were major human factor criteria for the comparison during the analysis stage of the experiment. In our analysis, we focused on finding information that can be used for the enhancement of ADIOS and the ITF alarm system.

The brief features of the ADIOS prototype and ITF alarm system, the experiment method, data analysis and evaluation results are described in that order.

ADIOS PROTOTYPE

ADIOS is being developed to support the development of the advanced compact workstation for Korea's next generation nuclear power plants (KNGR). ADIOS will have a general alarm system function integrated with process monitoring, diagnostic functions and control supports, in order for operators to understand the large amount of plant information, diagnose the cause of plant upsets, and control the safety function in a timely manner. A prototype of ADIOS was developed to have the typical alarm function [1].

Figure 1 shows the configuration of the ADIOS prototype. ADIOS receives source alarms from a plant simulator and processes the source alarms by using the predefined schemes for alarm prioritization, suppression, classification, etc. The resulting alarm information is displayed at the VDT-type operator interfaces which consists of two schematic displays, an alarm list display, and alarm tile displays.

ADIOS alarm processing

Alarm Classification: ADIOS classifies incoming alarms into plant alarms, process alarms, and equipment alarms. A plant alarm is related to overall plant status such as reactor trip, radiation releases, and earthquakes. A process alarm is an alarm caused by setpoint excess. An equipment alarm is used for equipment malfunctions or failure. Alarms that don't require immediate operator attention, such as equipment status alarms, are coded to be discerned from process alarms.

Mode Dependency: Alarms are suppressed according to operation mode, equipment status, multi-setpoint level precursors, and cause-effect relationships. This concept is used to prevent operators from being overloaded and distracted by many unimportant alarms[2].

Prioritization: A prioritization scheme in three levels is used in ADIOS. Alarms related to the reactor trip in 10 minutes have priority 1. Priority 2 alarms for reactor trip after 10 minutes. Alarms which could be mitigated without operator action, such as those caused by instrument drift, are categorized into priority 3. Red color is used for priority 1, yellow for priority 2, and white for priority 3. Plant process evolution can change the priority levels of alarms dynamically.

ADIOS alarm presentation

ADIOS provides operating crew with alerting cues and more detailed alarm information including values, setpoints, causal alarms, and alarm sources than conventional alarm systems. Three VDT displays are used for alarm presentation in ADIOS: a primary system overview display, a secondary system overview display and an alarm list display (see figure 2.). The primary and secondary system overview displays have 10 sub-screens for their subsystems. The alarm list display consists of 3 different screens: time-ordered, priority-ordered, and system-based lists.

ITF ALARM SYSTEM

The human factors team of KAERI established the Integrated Test Facility (ITF). ITF is an environment for human factor experiments. ITF has a PWR-type nuclear power plant simulator, main and support test rooms with VDU-based HMIs(Human-Machine Interfaces), an experiment control room, human factors measurements as well as built-in alarm systems. HMIs of ITF include flat-panel displays for safety function monitoring, VDTs for hierarchical plant mimic screens and trend graphs, a large scale overview display, and soft control devices (mouse, trackball, and touchscreen)[3].

The ITF alarm system is comprised of VDT-based alarm list(time-ordered only, see figure 3.), alarm tile widows, and hardwired annunciator panels. ITF alarm system does not include advanced alarm processing features such as alarm reduction or prioritization.

EXPERIMENT

Scenarios

On the basis of event surveys and challenges to plant safety, three scenarios were selected for this study: a feedwater pump trip together with RCP sealing line leakage, a SGTR, and a loss of feedwater together with main steam isolation valve fail-close. Time windows for each scenario were defined before the actual experiment.

Subjects

Two operation crews (4 men) from a commercial NPP participated in this experiment. Performance differentials between subjects were ignored because they work at the same plant and have enough operating experience. Before the actual experiment, they were trained on the ITF with and without the ADIOS prototype.

Experiment Design

The randomized block design was chosen so that the number of scenarios were considered as the number of repetitions. Pairwised T-tests were performed to determine statistical significance. Time, error rate, and situation awareness were chosen as major evaluation criteria for operator performance.

Experimentation

There were two breaks for situation awareness data acquisition in each scenario. Video/audio recordings, physiological data, alarm events and operator action logs were automatically collected during the experiment for each scenario. After the experiment, interviews with the operators were performed to obtain subjective opinions. In general, one scenario took 40-50 minutes to complete.

Data Analysis

The ITF includes the DAEXESS (Data Analysis and Experiment Evaluation Supporting System) which enables analysts to analyze experimental data quickly and easily. In particular, DAEXESS provides functions for qualitative analysis that requires many types of data, such as video recordings, system and operator events, and workload data [4]. DAEXESS was used in this study for statistical (quantitative) and observational (qualitative) analysis of experimental data. Time and error rate were calculated on the basis of predetermined time windows for each scenario. Operator workload was determined by physiological signal processing. Data from the post-experiment interviews were summarized to find human factors discrepancies and items to be improved.

Analysis Results

Statistical analysis of the time and error rate resulted in no statistical significance. Although workload analysis was not performed because data from one experimental run was contaminated, the other data showed insignificant differences. Regarding situation awareness, we performed two statistical comparison tests: ADIOS vs. ITF alarm system and RO vs. TO, but the results were not significant in both tests.

CONCLUSION

Although it failed to find performance significance, important information on operators' preference to ADIOS and ITF alarm systems was identified through the interviews which confirmed the opinion by our video recording review.

- Color coding scheme of ADIOS is very useful to identify the cause of alarms. Priority-based and mode-dependent color coding was preferred by operators.
- Operators have difficulties in moving from an ADIOS display to ITF HMI screens. They recommended the integration of ITF HMI with ADIOS features.
- Operators tend to look at ADIOS overview displays to identify which systems have problems and then refer to ADIOS alarm list display to determine which alarm is the key-alarm.
- During the initial phase of events, operators try to identify the key-alarm for the events.
- Operators refer to the trend graphs of plant parameters to confirm their decision on plant status after the key-alarm is identified.
- Operators don't pay attention to any alarms other than the key-alarm when their immediate response is not required.
- Operators refer to an alarm list display on the course of mitigating plant events.

It seems to be necessary to integrate the ADIOS alarm system with ITF HMI screens and trend graphs. Contrary to our expectation that operators refer frequently to overview displays, an alarm list plays an important role in identifying the key-alarm during plant disturbances.

REFERENCES

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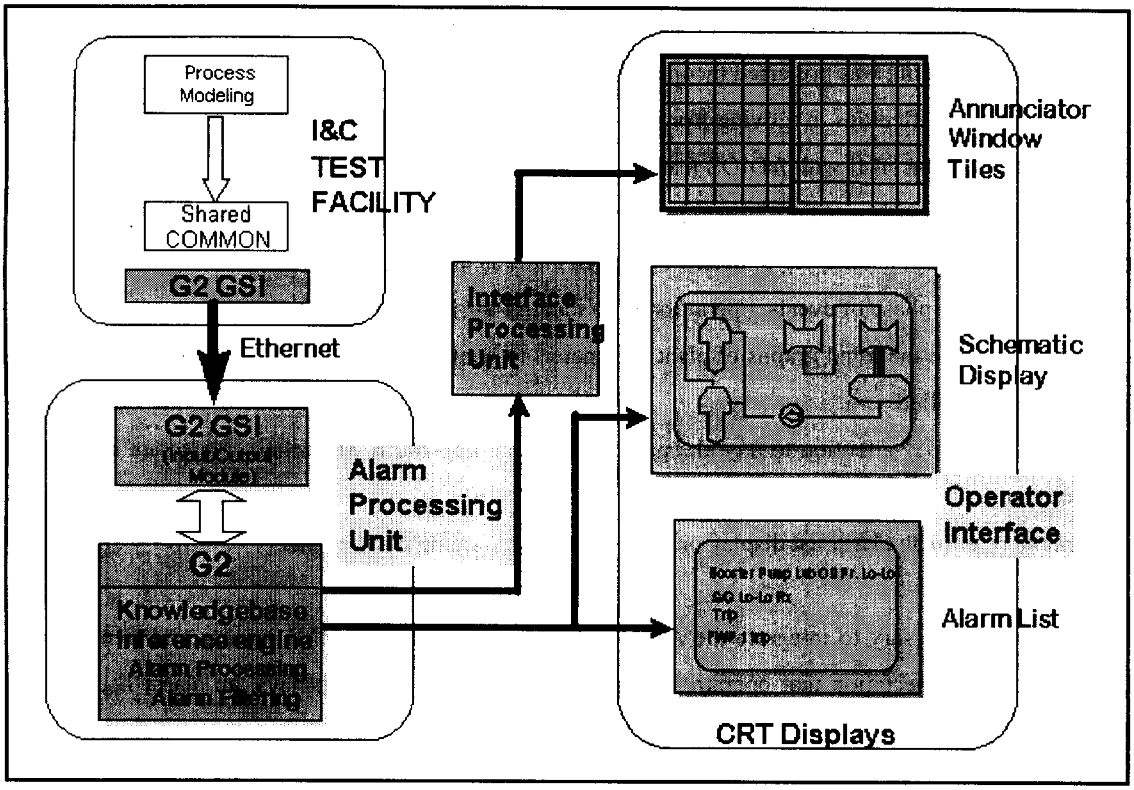


Figure 1. ADIOS Configuration

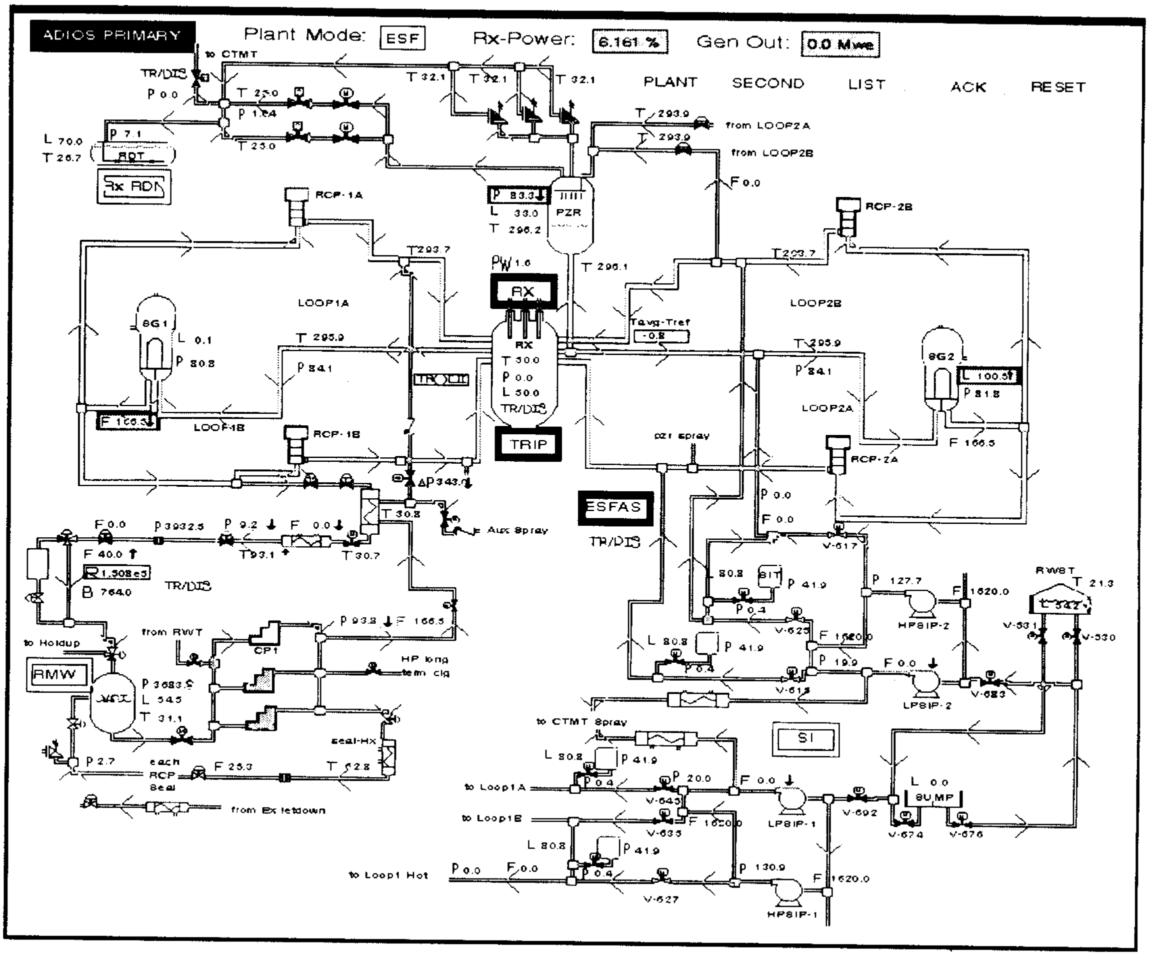
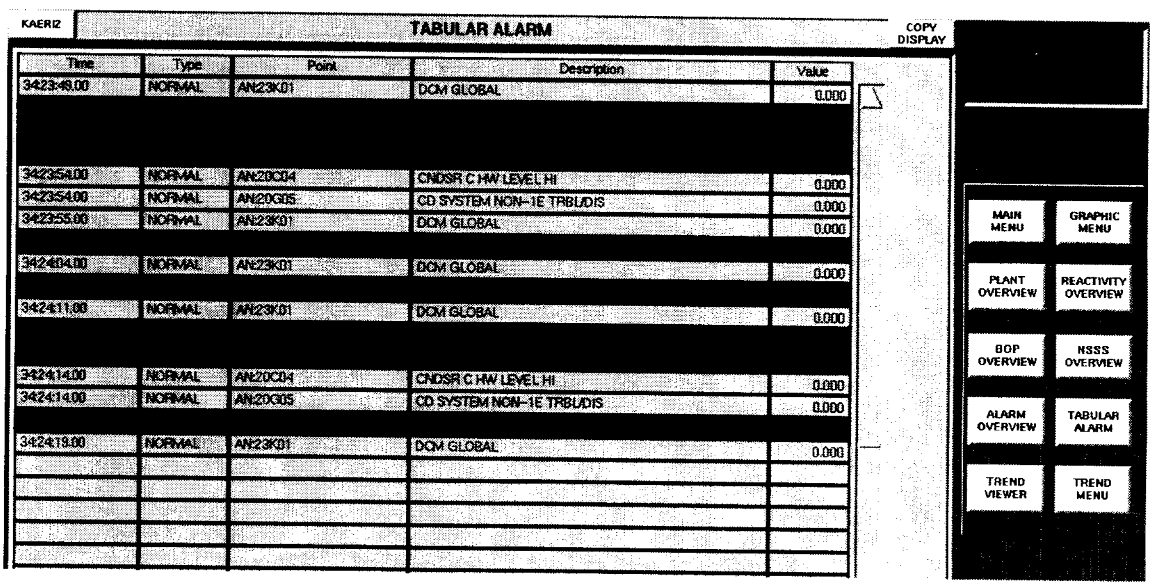


Figure 2. ADIOS Primary Overview Display



Time	Type	Point	Description	Value
3423:49.00	NORMAL	AN23K01	DCM GLOBAL	0.000
3423:54.00	NORMAL	AN20C04	CNDSR C HW LEVEL HI	0.000
3423:54.00	NORMAL	AN20G05	CD SYSTEM NON-1E TRBL/DIS	0.000
3423:55.00	NORMAL	AN23K01	DCM GLOBAL	0.000
3424:04.00	NORMAL	AN23K01	DCM GLOBAL	0.000
3424:11.00	NORMAL	AN23K01	DCM GLOBAL	0.000
3424:14.00	NORMAL	AN20C04	CNDSR C HW LEVEL HI	0.000
3424:14.00	NORMAL	AN20G05	CD SYSTEM NON-1E TRBL/DIS	0.000
3424:19.00	NORMAL	AN23K01	DCM GLOBAL	0.000

Figure 3. ITF Alarm List Display