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VALIDATION OF THE COMPUTERIZED ANNUNCIATION MESSAGE LIST SYSTEM (CAMLS)

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ABSTRACT

The Computerized Annunciation Message List System (CAMLS) is an annunciation system for use in the control rooms of nuclear generating stations. CAMLS will alert operators to changes in plant conditions that may impact on safety and production and help staff to effectively respond. CAMLS is designed to:

- provide a clear and concise overview of the current problems or faults in the plant,
- provide an overview of the current state of the plant in terms of automatic process and equipment actions,
- provide support for specific operational tasks, through either pre-configured or operator-configured annunciation displays, including:
  - rapid and efficient upset response,
  - plant stabilization,
  - problem diagnosis,
  - recovery action planning and implementation, and
  - rapid recovery from trip and return to power operation.

This paper summarizes the formal evaluation of the CAMLS in full-scope simulators at two different CANDU stations. The evaluation clearly establishes that CAMLS improves operator performance for most operationally significant tasks involving annunciation compared to existing CANDU annunciation systems. The implications of these improvements on safety margins, production costs, and human performance are significant.

1. INTRODUCTION

The Computerized Annunciation Message List System (CAMLS) is a computerized annunciation system for the control rooms of nuclear generating stations. CAMLS will alert operators to changes in plant conditions that may impact on safety and production and help staff to effectively respond. CAMLS is designed to:

- provide a clear and concise overview of the current problems or faults in the plant,
- provide an overview of the current state of the plant in terms of automatic process and equipment actions,
- provide support for specific operational tasks, through either pre-configured or operator-configured annunciation displays, including:
  - rapid and efficient upset response,

- plant stabilization,
- problem diagnosis,
- recovery action planning and implementation, and
- rapid recovery from trip and return to power operation.

To achieve this, several information processing, presentation, and interaction concepts were developed including:

- Alarm Processing Concepts/Features
  - definition of plant state (operating regions)
  - prioritization based on plant state
  - alarm conditioning based on plant state
  - reduced message volume through improved utilization of information
  - new types of alarms
- Alarm Presentation Concepts/Features
  - separation of faults (problems) and status messages into separate displays
  - ordering faults by order of priority
  - colouring messages by priority
  - retaining fault messages until fully acknowledged and returned-to-normal
  - backshading unacknowledged alarms (new and return-to-normal)
- Alarm Interaction Concepts/Features
  - single key acknowledge/reset
  - single tone on initial alarm occurrence
  - auto acknowledge for status messages

The result is that CAMLS:

- prioritizes relevant alarm data according to the consequence to the plant and the urgency for an operator response,
- adjusts the alarm presentation and priority with variations in the operating state of the plant,
- significantly reduces irrelevant alarm messages without losing key information,
- improves operator accuracy and speed of diagnosis and planning by providing organized information, and
- minimises distraction from important operational activities through less intrusive and demanding operator interactions.

CAMLS has two distinct components--two central overview displays and a desktop inquiry system (Annunciation Interrogation Workstation, AIW) [1].

These new design concepts for a computerized annunciation system have been developed, prototyped, and evaluated as part of a CANDU Owners Group (COG) research and development project. CAMLS has been assessed for operational performance over several upset scenarios in full scope simulators at two different operating CANDU stations. A formal validation process was used to arrive at statistically valid statements of comparative system performance between the current CANDU annunciation systems and CAMLS. The evaluations clearly establish that CAMLS improves operator performance for most operationally significant tasks involving annunciation compared to existing CANDU annunciation systems. The implications of these improvements on safety margins, production costs, and human performance are significant. This paper will summarize these activities and report on validation findings.

2. BACKGROUND

2.1 Current CANDU Annunciation

CANDU control rooms consist of an open room with instrumentation panels occupying two or more walls of the room. One wall contains instrumentation for the special safety, reactor, heat transport, boiler, feedwater, turbine and generator systems. Most of the routine plant operations and upset management can be performed from these panels and a central control desk. The other wall(s) contains instrumentation for on-power refueling, instrument air, process water, access control, and the electrical support and distribution systems.

The instrumentation panels are organized on a system basis and each panel contains annunciation indicators at the top, and conventional indicators (e.g., edgemeters, status lamps), computer displays and equipment controls (e.g., handswitches and analog controllers) throughout the rest of the panel area.

Annunciated information is displayed to operations staff by two centrally-located computer displays and a limited number of window annunciators at the top of each panel. The computer displays enable changes in the status of more than 6000 analog, contact inputs and calculated variables to be individually annunciated. However, these displays have a limited presentation capacity of only 20 messages each. If more annunciation messages are available for display at one time, the most recent messages overwrite the oldest ones.

The annunciation system supports operations staff well during normal operating conditions, and minor equipment failures or process upsets. During major plant upsets, process and equipment state changes can result in the annunciation of hundreds of messages. In some instances, this large number of annunciation messages may lead to “alarm flooding”. In such instances, operations staff use the panel window annunciators to track changes in the plant safety and production state, until the annunciation message presentation on the computer displays re-stabilizes.

CANDU operational practice assigns the control room crew full responsibility and authority to control all aspects of plant operation. To achieve specific safety and production goals, a number of high-level, and most middle- and lower-level, plant functions are automated. The operations staff are mostly in a supervisory role. Even so, many functions are carried out on a shared basis. Thus, there is a need for annunciation to help plant operators monitor the success of automated functions and to indicate to them to take over the performance of these functions if they fail.

2.2 CAMLS Interface Features

CAMLS provides interface features to better support operational needs. Operators require information quickly and efficiently for the various stages of operation of a standard upset response. Workload during the initial stages of the application of their upset response strategy (safety system check and plant stabilization) can be high; time is of the essence and reliance on memory should be avoided. To meet this challenge, a dedicated, centrally-located display of the faults and status alarm messages is required. These displays would replace the existing message screens in most CANDU stations. Specific presentation techniques adopted in the prototypes are summarized below [2, 3]

- Fault Message List - This display provides a single representation of the alarm state of the plant, for updating the operator's model of the state of the plant, and for identifying challenged operational goals and objectives based on the priority of various alarm conditions. The fault messages are ordered by priority, to ensure that the most important alarms are continuously available to the operators. Because the priority is context-dependent, it will aid in response planning. Further, because the order on the screen is by priority, it alleviates any concerns about colour-discrimination deficient operators or the failure of a colour gun.
- Status Message List - This display provides cues for required operational activities, and helps maintain awareness of significant automatic activities, so that operators can be prepared to diagnose problems in the context of the state of the whole plant. The messages are ordered by time sequence, to help operators identify and maintain the temporal order of changes in the state of the plant, and to maintain situational awareness of the plant's state and its direction.
- Expanded Text Messages Without Codes - This improves the readability and comprehension of the messages. The current message text in all CANDU stations is somewhat cryptic and full of reference codes, acronyms, and abbreviations. For the prototype system, many of the codes were removed and the text was expanded to eliminate abbreviations and obscure acronyms where possible. Work in this area continues.
- Colour Coding of Fault Messages for Priority - Colour coding provides a clear indication of the priority of a fault and provides a means of dual coding to indicate message importance.

During the other stages of the upset response (diagnosis, fault correction, and restoration of power production), the operators have more time to access annunciation information. However, greater detail and flexibility in the form of presentation of the information is required. For this, a facility dedicated to the interrogation and reorganization of annunciation information is required. The primary purpose of the facility is to provide support for specific operational tasks, and for diagnosis and decision-making. A secondary purpose for the facility is to reduce the time and effort required to access annunciation support information (alarm response procedures, alarm reference information, and possibly trends, flowsheets and source signal information).

3. SCOPE OF THE EVALUATION

Validation can be applied at many levels of detail and at various times during the development, design, and implementation cycle. This validation effort represents a comparative test of the system performance with certain changes to the annunciation message lists. Although the tests were performed on CANDU plants, specifically the New Brunswick Power Point Lepreau Generating Station (PLGS) and the Ontario Hydro Darlington Nuclear Generating Station (DNGS), it is anticipated that the results are equally applicable to any other CANDU or almost any other nuclear power plant in the world.

The validation activities were performed over the period from 1994 through 1996 and included three experiments. All experiments were a validation of the effectiveness of different components of CAMLS compared with similar components in the CANDU design for each host station.

3.1 Objectives Of The Validation

The overall objectives of the COG CAMLS validation program were to:

- perform validation and evaluation trials of various elements/concepts of the new annunciation strategy,
- incorporate feedback from the validation and evaluation trials to make further improvements in CANDU alarm annunciation,
- investigate and provide recommendations on the integration of the various annunciation facilities into existing station environments,
- establish benefits and risks of a specific configuration prior to implementation of design changes, and
- reduce the regulatory risk of a retrofit to existing stations.

The specific objectives of the different experiments were:

- Experiment 1 - Central Alarm Message Screens at Point Lepreau
  - Assess the effectiveness of CAMLS in supporting upset operations associated with different complexities of upset events.
- Experiment 2 - Annunciation Interrogation Workstation at Point Lepreau
  - Assess the effectiveness of the CAMLS AIW in supporting specific operator tasks associated with upsets as well as some normal operations.
- Experiment 3 - Central Alarm Message Screens at Darlington
  - Assess the effectiveness of CAMLS in supporting normal and abnormal operations associated with station startup and outage management, thereby ensuring that CAMLS is effective over all significant regions of plant operations.

- Assess and identify issues associated with crew usage of CAMLS (e.g., potential changes to crew member roles, communication, operational practices to achieve maximum operational benefits from CAMLS use).

3.2 Types Of Assessment

All validation efforts focused on comparing the existing station annunciation system with the complete CAMLS system concept across several scenarios and operating situations.

3.3 Degree Of Formality

The validation plans and reports included the definition of:

- performance hypotheses,
- design of scenarios to test the hypotheses and/or the selection of hypotheses to test that were compatible with the scenarios chosen,
- measures of performance consistent with the hypotheses,
- acceptance criteria for the measures selected,
- an experimental design that accounted for certain possible confounds, and
- a statistical analysis of the results leading to a degree of confidence in the acceptance or rejection of the hypotheses tested.

4. PERFORMANCE HYPOTHESES

4.1 Identification

A combination of the upset response strategies used at CANDU plants and a decision-making model framework [3] were used to identify possible performance hypotheses.

During earlier work on this project, several evaluations were carried out and a number of subjectively-based statements of performance enhancement were made by station-based reviewers of the work. These statements were identified and extracted as performance hypotheses to be tested in a more controlled and dynamic setting. In addition, several statements were made by the designers regarding potential performance benefits of the system, and these statements were also extracted and used as performance hypotheses to be tested. Finally, existing station utility staff and design organization staff were polled for input to the kinds of measures necessary to assess annunciation system design. These were then added to the set of hypotheses as appropriate.

4.2 Hypotheses Identified

A summary of the hypotheses identified for the experiments follows. Compared to existing station annunciation, CAMLS will lead to:

- improved detection of:

  - potential alarms conditions before they are alarmed (improved plant state prediction due to improved situation awareness)
  - alarms identifying improperly configured systems
  - alarms not related to a primary event or condition
  - automatic actions
- improved diagnosis of:
  - trip casual factors
  - root causes of upsets
  - current plant state
  - future state of the plant
  - abnormal plant process disturbances
  - safety concerns
  - production concerns
- improved decision-making:
  - for order of priority for response to alarms
  - for procedure selection
- task specific improvements:
  - reduced time to access information for alarm comprehension and response
  - reduced time to access to information on a specific alarm
  - improved time to access historical information
  - improved transfer of information during shift change-over
  - less demanding and easier acknowledgment approach
  - reduced demands on user memory
  - improved access to alarm response procedures or alarm detail.

The Results section of this paper includes the specific hypotheses selected and tested for the various validation exercises.

5. MEASURES OF PERFORMANCE

Meister [4] outlines a process for the derivation of measures of performance. This process consist of identifying mission dimensions, selecting a subset of mission dimensions as performance criteria, deriving measures for each criteria, and finally establishing standards. A similar outline has been used in this work to identify dimensions, measures, criteria, and standards.

Dimensions are the underlying performance issues that hypotheses are based on and represent key mission statements of the system. Some of the dimensions identified were understanding, time, accuracy, and errors. These dimensions have been chosen as the criteria because they best reflect overall system performance. The relevance and importance of each potential criterion was assessed by asking how success of, or failure of, a particular criterion affects system performance. For example, because a nuclear power plant is a complex system, timely response is important for the safe and effective operation of the plant. Thus, timely response is an important criterion. Since operators have to perform a variety of tasks or functions, there may be multiple criteria. It is possible that one criterion suggests effective performance and yet another criterion may suggest the opposite. This is understandable since operators may favour performance associated with one criterion at the expense of another to suit the operational goals and situation. In this paper, the terms performance hypothesis is used as an equivalent to dimensions.

The measures were derived based on the hypotheses identified. The nature of the measures defined was consistent with the objective to assess system effectiveness and in accord with the scenarios selected. The measures identified were based on the dimensions/hypotheses identified. The type of the measures used are consistent with assessing the system's effectiveness.

The standards/acceptance criteria used for this test were based simply on a comparative approach of the measure between the existing CANDU annunciation and CAMLS. Typically, the acceptance criteria were inherent in the measure collected and only a significant indication of obvious improvement was required. This is in contrast to acceptance criteria based on absolute measures of performance that are difficult, if not impossible, to obtain and prove.

5.1 Measures Identified

The measures for the experiments were drawn from subjective and objective assessments:

- Subjective - How do you rate the annunciation system's:
  - Ease of use or difficulty for acknowledgment?
  - Ability to keep you aware of the state of the plant?
  - Ability to keep you informed of important alarms independent of the primary upset?
  - Demand on your memory?
  - Ability to keep you informed of the state of the automatic actions during an upset?
  - Support for root cause diagnosis?
  - Ease of access to alarm response procedures?
  - Likelihood of making an error in selecting an alarm response procedure?

- Objective - Categories of measures
  - Early and continuing plant state awareness.
  - Identification of problems (including initiating, related, secondary, and tertiary).
  - Awareness of plant state trend.
  - Awareness of plant safety concerns.
  - Awareness of plant production concerns.

5.2 Data Collected

For all the experiments, the following types of data were collected:

- Subjective
  - Anchored Subjective Rating Scales
    - Subjects
    - Subject Matter Experts
  - Subject system-comparative questionnaire
- Objective
  - Scenario Specific Measures of Performance
    - Number of items identified
    - Time taken to perform or complete a task/action

6. PERFORMANCE ACCEPTANCE CRITERIA

The only performance criteria used for all experiments was a measure of effectiveness based on the degree of improvement over the existing designs.

7. THE EXPERIMENT

7.1 Experimental Factors

There are three basic types of independent variables [5]:

- System characteristics,
- User characteristics, and
- Environment characteristics.

For the purpose of this validation effort, independent variables have been identified, for the most part, related to system characteristics. This is because the purpose is to evaluate the effectiveness of the new annunciation concepts developed in previous years. One experimental system factor and one environmental factor were used.

For the initial validation trials performed during 1994/95, the focus was on the effects that system characteristics have on subject performance in order to compare the performance of the CAMLS with existing CANDU annunciation systems. The use of scenarios as an independent variable was required to establish whether the results might, in fact, be scenario dependent within the scope of the scenarios used. As a result, the independent variables were simplified in the following manner:

- the system characteristic identified was the type annunciation of system being used,
- the user characteristic was fixed as the licensed operator (Senior Power Plant Operator, SPPO, at PLGS and the Authorized Nuclear Operator, ANO, at DNGS) and was the subject in the experiments, and

- the environment characteristic was the scenario used.

The selection of scenarios was based on the authors' experience of plant operations as well as feedback from training personnel from PLGS and Darlington.

For Experiments 1 and 2 at Point Lepreau, two upset scenarios were selected:

- Loss of Class IV power (LCIV) due to the failure of the system service transformer and a loss of condenser vacuum leading to turbine trip, and
- Loss of boiler feedwater (LOFW) due to the wrong level control valve being removed from service through a field maintenance action.

A third upset scenario, reactor trip due to channel over power, was used for training subjects on the CAMLS system. The two test scenarios were selected to represent different levels of complexity in terms of the amount of annunciated information, the number of actions required from the operators, and the seriousness of the transient.

For Experiment 3 at Darlington, two simulator scenarios were used:

- Reactor trip and recovery - This involved a heat transport pump trip as the initiating cause for a reactor stepback. Several additional process disturbances and equipment failures were inserted to provide means for testing the ability of the CAMLS system to make the operating crew aware of the plant configuration and state.

- Reactor startup from outage - This involved a change in heatsink state from shutdown cooling to boilers as the plant is prepared for return to power generation. The scenario involves a 30 minute period beginning just after criticality is reached and ending prior to the heatup of the heat transport and secondary process systems.

7.2 Experimental Design

7.2.1 Experiments 1 and 3 - Central Alarm Message Screens at Point Lepreau and Darlington

The two annunciation systems (CAMLS, Existing CANDU) and the 2 scenarios at each station, resulted in 2x2=4 treatments (factors-levels combination). Thus, the experiment was a two factorial (2x2) completely randomized design with repeated measures. Tables 1 and 2 describe the experimental designs used for each of Experiments 1 and 3.

Table 1: Experiment 1 - Experimental Design.

Annunciation System Design	Scenario Order	Subjects
Existing C-6 Design	LCIV - LOFW	1st half subjects of Group 1
Existing C-6 Design	LOFW- LCIV	2nd half subjects of Group 1
COG CAMLS Design	LCIV-LOFW	1st half subjects of Group 2
COG CAMLS Design	LOFW- LCIV	2nd half subjects of Group 2
Note: LCIV = Loss of Class IV scenario and LOFW = Loss of Feed Water Scenario		

Table 2: Experiment 3 - Experimental Design.

Trial 1	Trial 2	Subjects
COG CAMLS Design/Heat Sink Pump Trip	Darlington Design/Heat Sink Transition	1st half subjects of Group 1
COG CAMLS Design// Heat Sink Transition	Darlington Design/Heat Sink Pump Trip	2nd half subjects of Group 1
Darlington Design/Heat Sink Pump Trip	COG CAMLS Design/ Heat Sink Transition	1st half subjects of Group 2
Darlington Design/Heat Sink Transition	COG CAMLS Design/Heat Sink Pump Trip	2nd half subjects of Group 2

7.2.2 Experiment 2 - Annunciation Interrogation Workstation at Point Lepreau

The 2 operator support systems (AIW, Current paper-based approach) were investigated, and the LOFW scenario resulted in 2x1=2 treatments (factors-levels combination). Thus, the experiment was a one factorial (2x1) completely randomized design with repeated measures.

Each subject was tested under the LOFW scenario with both systems. Subjects were randomly assigned to two groups. Subjects in Group 1 used the current paper-based approach first and then the AIW. Subjects in Group 2 used the AIW first and then the current paper-based approach. This was done to minimize any learning effects carry over from using the same scenario. Table 3 shows the experimental design used.

Table 3: Experiment 2 - Experimental Design.

Resources Used for Task	**Subjects (6 in total)**
Current paper-based approach	Group 1 - 3 subjects
AIW support	Group 1 - 3 subjects
AIW support	Group 2 - 3 subjects
Current paper-based approach	Group 2 - 3 subjects

7.3 Experimental Procedure

7.3.1 Experiments 1 and 3 - Central Alarm Message Screens at Point Lepreau and Darlington

Each subject's session included, in order, 10 minutes of training in the new system (CAMLS), an experimental trial using the new system under one of the two scenarios (25 min.), a 5 minute simulator reset and data collection in parallel with collection of subjective measures from the subject, an experimental trial using the existing annunciation system with the other scenario (25 min.), and another 5 minutes simulator reset and data collection in parallel with collection of subjective measures from the subject. The entire session took about 1 hour.

Operators were told at the beginning of each session that they were to perform the role of SPPO (PLGS) or ANO (DNGS), and that they were supported by a Power Plant Operator (PPO), a Field Senior (FS-SPPO) and Shift Supervisor (SS) (performed in actor roles). Subjects were drawn from the control room shift complement, refresher training programs, personnel in-training for licensed positions, and from licensed station staff not on shift. The supporting roles were played by members of the training staff and the validation team.

During each scenario, subjects were asked by the SS a series of questions about the plant’s state, problems, state trend, safety concerns and production concerns. The interaction between the subjects and the SS was designed to be consistent with normal operational practices. The questions were scenario specific and the answers were recorded in checklists. Answers provided that were not in the checklist were noted, but were not included in the data analysis. For the LOFW scenario, the time taken for the diagnosis of the root cause of the upset was recorded. After each scenario, the subjects completed a series of anchored subjective rating scales. The subjects were asked to check anywhere along the scale and to use the behavioural descriptor as a guide. After each session, the operator was asked to fill a second questionnaire that provide direct comparative assessment of the support provided by CAMLS or the current central annunciation system.. Half the subjects did Scenario 1 first and half did scenario 2 first. Each entire session for each subject took approximately about an hour. The subjects were split into two groups consistent with the previously described experimental design.

The checklist items, subjective scales, and the questionnaire were defined based on the performance hypotheses. The schedule of activities is further described in reference 6.

7.3.2 Experiment 2 - Annunciation Interrogation Workstation at Point Lepreau

Operators were told to assume they were on shift in the control room and that the plant would experience an upset. They were asked to perform a number of tasks associated with upset diagnosis and response recovery. The tasks performed represented a mix of tasks that could be performed by the Senior Power Plant Operator, Assistant Power Plant Operator, or Shift Supervisor. Finally, the operators were told that for some tasks they would be asked to use the normal control room resources. For other tasks they would be asked to use the Annunciation Interrogation Workstation. The subjects were split into two groups.

Tasks selected for testing were based on the following performance hypotheses:

- The AIW provides better support for the task of accessing an alarm response procedure than the use of paper-based operating manuals (Task 1).
- The AIW provides better support for the task of confirming the cause of a trip than an examination of paper-based annunciation logs (Task 2).
- The AIW provides better support for tasks where alarm reference or detail information needs to be recalled rather than an examination of operating manuals and reference flowsheets (Tasks 3 and 5).
- The AIW provides better support for the task of determining the cause of the upset than an examination of paper-based annunciation logs (Task 4).
- The AIW provides better support for the task of confirming shutdown system trip inhibit actions than an examination of paper-based annunciation logs (Task 6).
- The AIW provides good support for the task of examining the alarm state and history for a specific system (Task 7).

The schedule of activities is further described in reference 6.

8. DATA ANALYSIS

Since this is a comparative evaluation, the focus in testing is whether the observed difference between the means of the two systems is statistically meaningful. The implication of this is that one system can be statistically better than the other. A t-test was used for testing the difference between the two population means, assuming independent samples and unequal variances.

It should also be noted that the nature of experimentation in the nuclear industry is that the subject population is small resulting in a small value for “n” in statistical calculations. This has to be weighed with the fact that large percentages of the total population itself were included in the trials. To take this into consideration, lower confidence intervals (CI) were considered to establish statistical significance.

9. RESULTS

Each of the following sections provide a summary of the data collected for each of the measures and categories of data.

9.1 Experiments 1 and 3 - Central Alarm Message Screens at Point Lepreau and Darlington

9.1.1 Objective Results

Results are shown in Tables 4 through 6.

Table 4: PLGS Objective Checklist.

	% Improvement with CAMLS	
Category	**Loss of Class IV**	**Loss of Feedwater**
Plant state	**17.31% @ 75%CI**	9.52%
Problems	**36.54% @ 85%CI**	**41.67% @ 95%CI**
State Trend	**38.89% @ 95%CI**	**4.17% @ 90%CI**
Safety Concerns	**-27.08% @ 80%CI**	**37.5% @ 80%CI**
Production Concerns	**27.78% @ 80%CI**	14.58%

Note: Larger Bold Font indicates Statistically Significant
CI - Confidence Interval

Table 5: DNGS Objective Checklist - Stepback on Heat Transport Pump Trip and Recovery Scenario.

	% Improvement with CAMLS	
Category	**ANO**	**SS**
Plant state	**17.00% @ 90%CI**	4.17%
Problems	**19.64% @ 90%CI**	**10.83% @ 95%CI**
State Trend	**6.25% @ 75%CI**	0.00%
Safety Concerns	**54.17% @ 95%CI**	**18.75% @ 75%CI**
Production Concerns	**14.06% @ 90%CI**	**11.11% @ 90%CI**

Table 6: DNGS Objective Checklist - Startup Heat Sink Transition Scenario.

Category	% Improvement with CAMLS	
	ANO	**SS**
Plant state	**20.00% @ 95%CI**	**23.14% @ 85%CI**
Problems	**31.06% @ 90%CI**	**19.10% @ 90%CI**
State Trend	3.75%	**30.00% @ 85%CI**
Safety Concerns	**20.00% @ 85%CI**	**10.00% @ 80%CI**
Production Concerns	**63.00% @ 95%CI**	**52.00% @ 95%CI**

Note: Larger Bold Font indicates Statistically Significant
CI - Confidence Interval

Comment: The degradation in performance in identifying safety concerns during one scenario at PLGS can be attributed to:

- the experimental elimination of the hard-wired safety-based window alarms from the simulator during trials with CAMLS, and
- a relationship/confound between the scenario chosen and the source of information indicating the safety state of the plant.

Although the elimination of the windows was required to accurately measure the impact of the use of CAMLS, it is not intended nor desired to eliminate the window annunciator alarm system component in future implementations.

9.1.2 Subjective Results

Results from the anchored rating scales are shown in Tables 7 and 8. Results from the questionnaires are shown in Tables 9 and 10.

Table 7: PLGS Rating Scales.

Rated Topic	**% Improvement Indicated with CAMLS for Loss of Class IV**
How do you rate the ease of use or difficulty of the acknowledgement system?	**31% @ 85%CI**
How do you rate the annunciation system's ability to keep you aware of the state of the plant?	**22% @ 85%CI**
How do you rate the system's ability to keep you informed of important alarms independent of the primary upset?	**24% @ 85%CI**
How do you rate the annunciation system's demand on your memory (e.g., have to remember past alarms, have to remember alarm BSI and alarm ID's)?	**35% @ 95%CI**
How do you rate the system's ability to keep you informed of the state of the automatic actions during an upset?	**38% @ 95%CI**
How do you rate the ease of access to alarm response procedures?	19%
How do you rate the likelihood of making an error in selecting an alarm response procedure?	11%

Note: Larger Bold Font indicates Statistically Significant
CI - Confidence Interval

Table 8: DNGS Rating Scales.

	Stepback on Heat Transport Pump Trip and Recovery		Startup Heat Sink Transition	
Rated Topic	**ANO % Improvement Indicated with CAMLS**	**SS % Improvement Indicated with CAMLS**	**ANO % Improvement Indicated with CAMLS**	**SS % Improvement Indicated with CAMLS**
Alarm acknowledgement usability	**23.33% @ 90%CI**	2.78%	**13.75% @ 95%CI**	3.06%
Support for user awareness of plant state	**21.25% @ 95%CI**	**13.19% @ 90%CI**	**32.67% @ 95%CI**	**14.67% @ 90%CI**
Support for user awareness of safety state	**29.17% @ 95%CI**	6.53%	**16.00% @ 90%CI**	**12.67% @ 90%CI**
Support for user awareness of important fault alarms	**30.42% @ 95%CI**	**12.78% @ 85%CI**	**15.92% @ 95%CI**	**12.33% @ 80%CI**
Reduced demand annunciation imposes on user memory	**20.42% @ 90%CI**	**23.89% @ 95%CI**	**38.17% @ 95%CI**	**31.25% @ 95%CI**
Support for user awareness of automatic actions	**15.83% @ 90%CI**	**13.19% @ 90%CI**	**26.25% @ 95%CI**	**26.25% @ 95%CI**
Support for root cause diagnosis	**29.17% @ 95%CI**	**25.56% @ 95%CI**	**33.33% @ 95%CI**	**30.44% @ 95%CI**
Ease of access to alarm response procedures	**39.03% @ 95%CI**	**32.22% @ 95%CI**	**30.92% @ 95%CI**	**36.17% @ 95%CI**

Note: Larger Bold Font indicates Statistically Significant
CI - Confidence Interval

Table 9: PLGS Subjective Results - Comparative System Performance Questionnaire.

Question Category	% Favouring CAMLS
The CAMLS message list system is better at presenting the operator with important alarms that are independent of the main upset.	100%
The separation of alarms into two groups faults and status improves the identification of problems to be address and better maintain an awareness of the automatic actions in the plant.	100%
The CAMLS message list system offers a more simple and effective acknowledgement approach.	83%
The CAMLS message list system approach of presenting faults in order of priority is more effective in alerting users to the most important problems at any instant.	100%
The continuous presentation of active fault alarms is not as effective as the existing annunciation system.	100%

Note: This represents results from combined scenarios: Combined Scenarios - Loss of Class IV/Loss of Feedwater
CI - Confidence Interval

Table 10: DNGS Subjective Results - Comparative System Performance Questionnaire.

	% Favouring CAMLS	
Question Category	**Startup Heat Sink Transition**	**Stepback on Pump Trip and Recovery**
Fault/status separation improves problem identification and awareness	93%	100%
Listing faults by priority is more effective in alerting users to problems	93%	75%
CAMLS is better at highlighting important alarms independent of main upset	87%	92%
Continuous presentation of faults is more effective	93%	58%
Event screen provides a useful summary of major plant changes	87%	92%
CAMLS offers a simpler and more effective alarm acknowledgment	87%	75%
The AIW provides improved tools for alarm diagnosis and response planning	80%	75%
Electronic access to alarm reference information is a useful addition to console	87%	83%

9.2 Experiment 2 - Annunciation Interrogation Workstation at Point Lepreau

9.2.1 Objective Results

Figure 1 shows a summary of the results of the timing data.

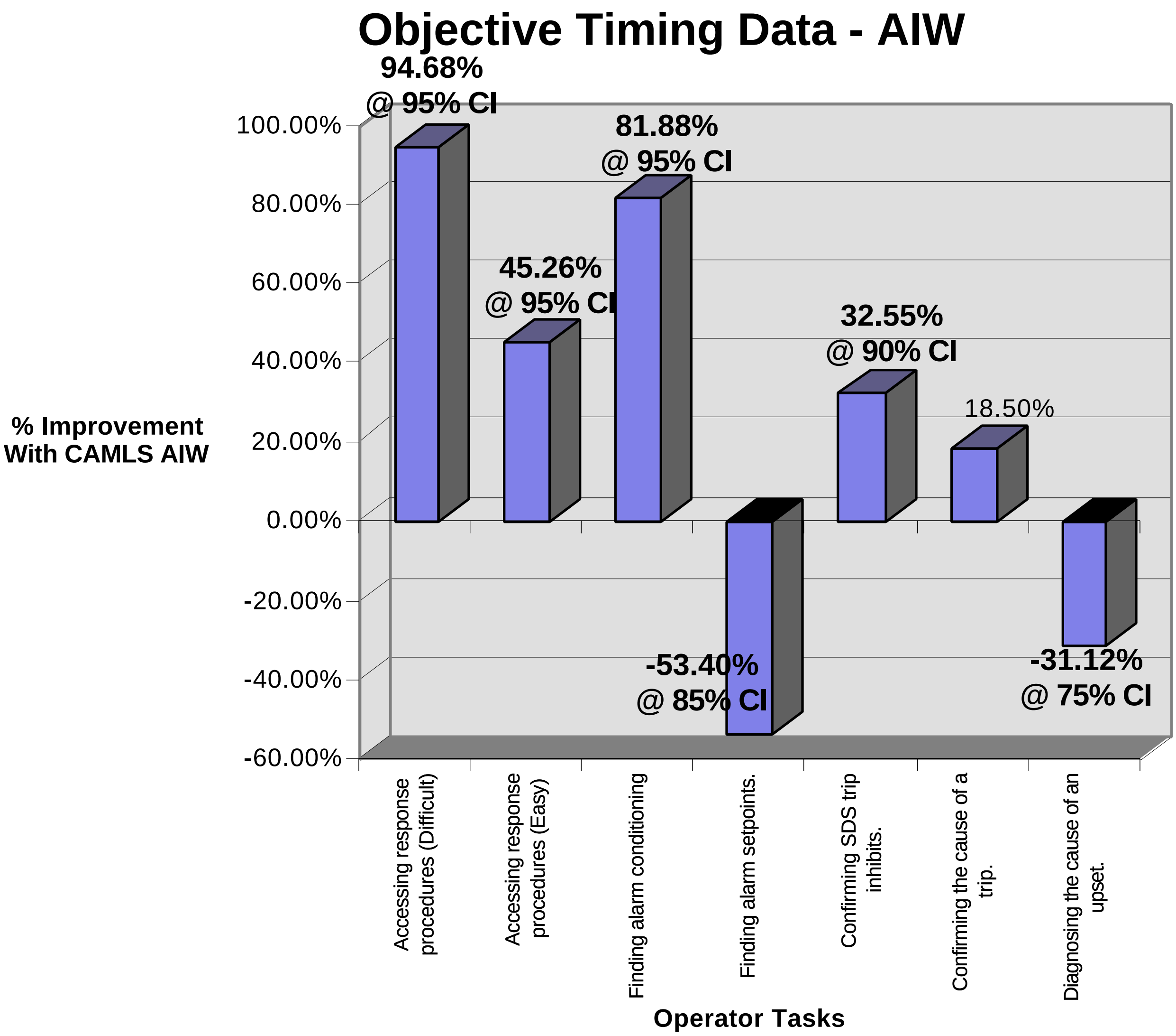

Figure 1: AIW Validation - Objective Timing Results.

Note: Larger Bold Font indicates Statistically Significant and CI - Confidence Interval

Comment: The negative result for "Finding alarm setpoints" was unexpected. It had been expected that the AIW would allow operators to find the setpoint for a contact input alarm faster than with the current approach. This is because the information to be found was located in the AIW alarm response procedure display. Since, for a similar task, the AIW provided faster access to alarm response procedures, the subjects should have also found the setpoint for a contact input alarm faster. It was reasoned that due to the lack of training and experience with using the AIW, they did not know where to look for that information in the alarm response procedure display (a display they had no trouble getting to).

Comment: The decrease in time to diagnose the cause of the upset with the AIW, in comparison with paper-based methods, was unexpected. This is a diagnostic task which is supported by access and visual search through specific sections of a historical annunciation log. With the AIW, the access portion of the task was simplified, however subject performance was impeded in the visual search task due to unfamiliarity with display scrolling controls.

9.2.2 Subjective Results

Figure 2 shows a summary of the results from the anchored rating scales, while Figure 3 shows the results from the questionnaires.

10. INTERPRETATION OF THE DATA

A key assumption was considered in interpreting and considering the resultant data:

- The small amount of training for subjects on the CAMLS system should result in poorer performance when using CAMLS, in comparison to performance using the existing station design, than would be expected with more complete training in the use of CAMLS.

10.1 Experiments 1 and 3 - Central Alarm Message Screens at Point Lepreau and Darlington

Based on these results, it has been shown, with statistical confidence, that the CAMLS Central Annunciation Message Lists without the existing window tiles as compared to the existing CANDU central message lists with the window tiles, enhances operator performance by improving:

- the probability that significant alarms are detected,
- the probability of detecting significant problems,
- the probability of detecting alarms secondary or independent of the primary or initial upset,
- awareness of plant state,
- the performance of operators by reducing the demand on operators' short term memory and the resulting mental workload,
- awareness of automatic actions in the plant, and
- the availability of operators for important activities by reducing distracting and unnecessary interaction with the annunciation system.

The first three points noted above have direct safety and economic implications. They can be said to point to an increase in the margins to safety of a CANDU plant and a decrease in

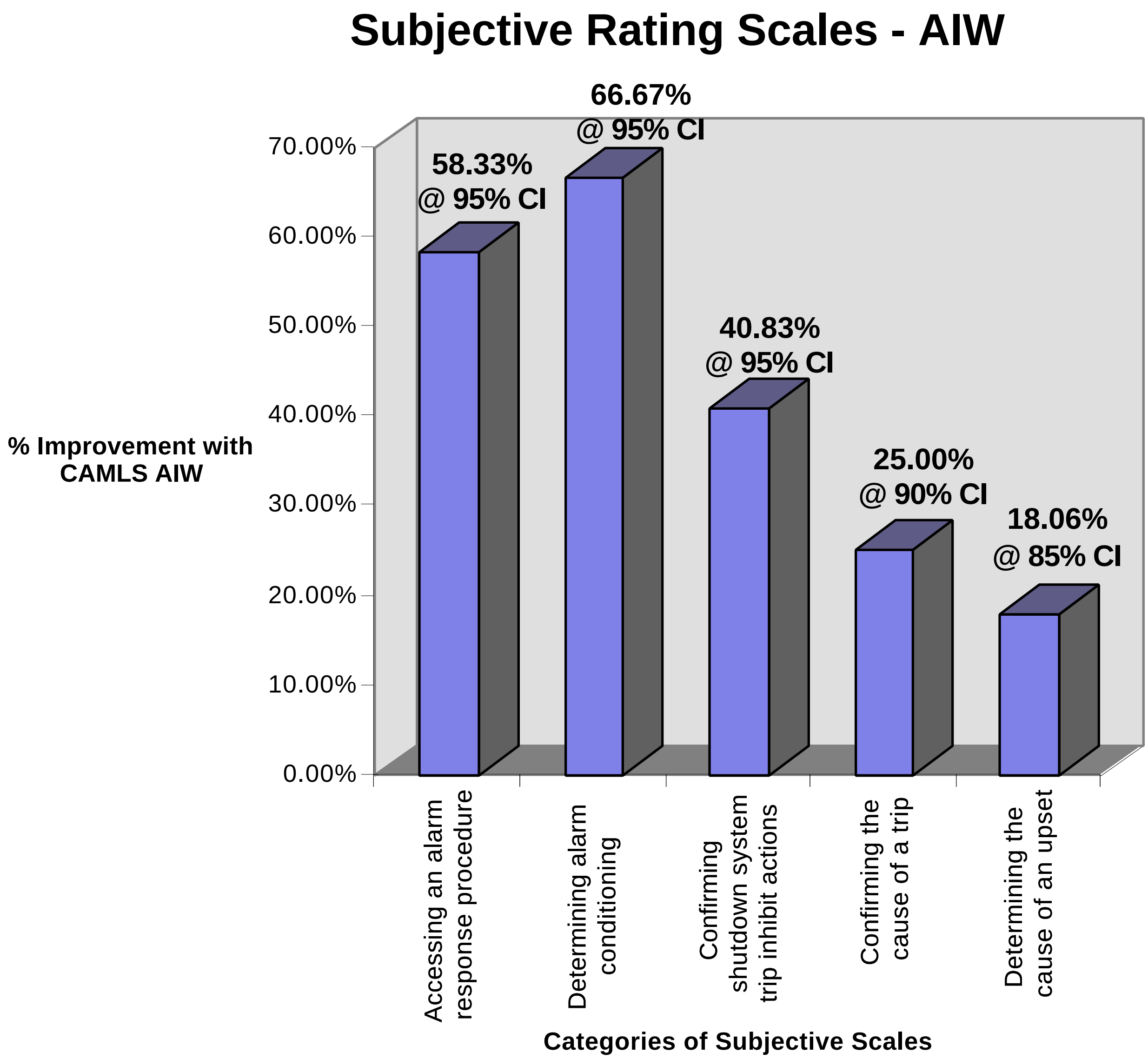

Figure 2: AIW Validation - Subjective Rating Scale Results.

Note: Larger Bold Font indicates Statistically Significant and CI - Confidence Interval

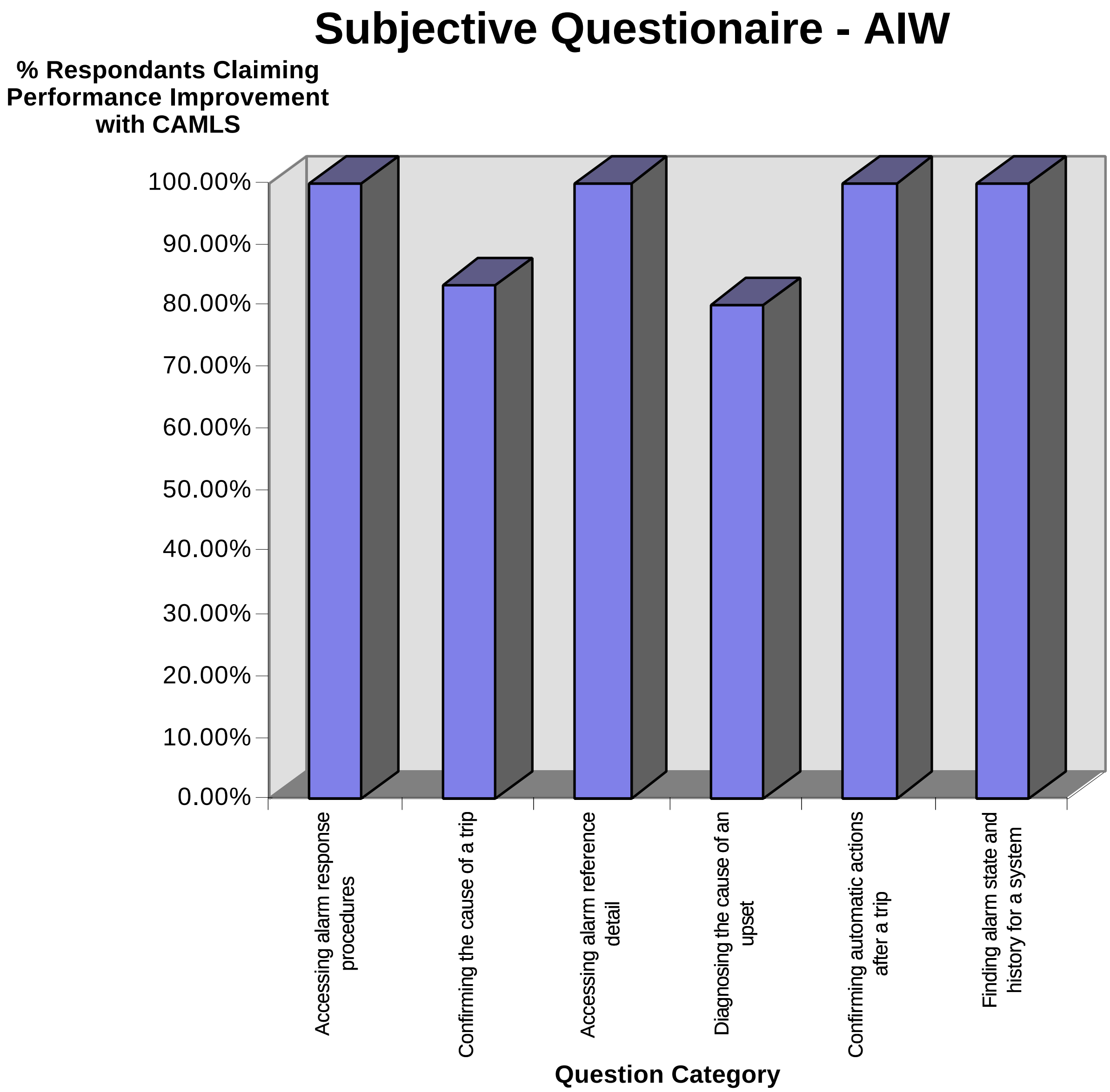

Figure 3: AIW Validation - Subjective Questionnaire Results.

the probability of plant trips and equipment damage thereby resulting in an economic saving. The last four points indicate an improvement in human performance in the system. At this point, the link between improved human performance in these areas and improved safety and economics is tenuous within the context of this evaluation. However, research in the international aviation industry clearly points to a strong link between these types of measures and the eventual measures of safety and cost effectiveness.

CAMLS achieves this by:

- prioritizing relevant alarm data according to the consequence to the plant and the urgency for an operator response,
- adjusting the alarm presentation and priority with variations in the operating state of the plant,
- significantly reducing irrelevant alarm messages without losing key information,
- providing operationally organized information, and
- preventing unnecessary operator distraction from important operational activities.

It is expected that other improvements with CAMLS have been suppressed by a lack of training and experience with the system and that even greater gains in performance are expected with an operational system. Note that the lack of time for adequate training is a result of the general lack of availability of operators and is a practical reality in the industry.

10.2 Experiment 2 - Annunciation Interrogation Workstation at Point Lepreau

Based on these results, it has been shown, with statistical confidence, that the CAMLS Annunciation Interrogation Workstation as compared to the existing CANDU 6 support for annunciation related tasks, improves operator performance by directly supporting tasks for which there was no previous explicit support. Given appropriate training and experience with the AIW, it is believed that the inconsistencies in results would shift to show that the facility provides better support for procedural and information search tasks in the areas of:

- trip cause identification,
- upset cause identification,
- confirmation of automatic responses,
- confirmation of successful safety system trip including trip inhibits,
- access to alarm response procedures, and
- access to alarm conditioning, setpoint, and other related information.

It is clear that many of the benefits of the AIW are independent of the benefits of the improvements to the central annunciation system design.

11. CONCLUSION

New design concepts for computerized annunciation have been developed, prototyped, and evaluated. As part of a COG research and development project, a Computerized Annunciation Message List System (CAMLS) has been assessed for operational performance over two upset scenarios. A formal validation process was used to arrive at statistically-valid statements of comparative system performance between the current CANDU annunciation system and the COG-developed CAMLS. The evaluation clearly establishes that CAMLS improves operator performance for most operationally significant tasks involving annunciation compared to existing CANDU annunciation systems. The implications of these improvements on safety margins, production costs, and human performance are significant.

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