AN APPROACH FOR IMPROVING ALARM PRIORITIZATION ANALYSIS

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Abstract

A new function-based approach for alarm prioritization is proposed that has significant advantages over the traditional annunciation methods. In this new approach, alarms are considered to be health indicators of a plant function. Instead of individually prioritizing each alarm, the function-based approach identifies the importance, to the plant, of the loss of each plant function. Alarms associated with each function then inherit the function’s priority in the plant’s operation.

This paper outlines the opportunity for enhancements to current alarm prioritization approaches, discusses the basis for organization of plant functions, describes the proposed prioritization approach, and summarizes advantages and our initial experience. In addition, the application of common off-the-shelf database technology, used to provide a design environment for supporting this approach, is described.

Introduction

A new function-based approach for alarm prioritization is being developed by AECL. This approach offers a generic alarm prioritization solution for all CANDU plants, both new designs and existing stations. The alarm prioritization concepts and improvements comprising the approach extend those developed under CANDU Owner's Group sponsorship in the years 1994 to 1996.

The function-based alarm prioritization approach is based on three steps:

- Step #1 - Organization and identification of plant functions (specifically, those functions involved with annunciation),
- Step #2 - Prioritization of plant functions, by operational importance, for each plant operational state, and
- Step #3 - Assignment of individual alarm priorities based on their association with a specific plant function.

This approach employs the same alarm importance determination reasoning practiced by station Operations staff and offers the promise of achieving more operationally relevant and consistent priority assignments with significantly less analytical effort. Operating and training documentation from several stations served as reference material to ensure that

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the prioritization approach and results matched existing station operational practices. In addition, it was decided that the function-based approach should compliment the system distribution implemented in existing station hardwired annunciation systems (i.e., the panel window tiles).

Since many plant functions are generic from station to station, it is expected that the results of this approach will be applicable to all stations. Thus, this approach is expected to reduce the design and commissioning cost of near-term annunciation system improvements in both station retrofit and new plant designs.

Background

CANDU plants use computer-based annunciation message systems to alert operators to both abnormal operating conditions (i.e., fault messages), and changes in plant configuration which occur as the result of the automatic responses of automation (i.e., status messages). Current annunciation systems are implemented as part of the plant digital control computer software and contain many thousand alarm messages. Annunciation is based on a three level alarm importance classification (i.e., safety, major, and minor) with chronological presentation of alarm messages on two large interconnected alarm displays located in the center of the control room. This approach satisfies Operations needs in periods of stable, full-power operation, but during other operational states the annunciation system is less supportive.

Current annunciation systems use a single, fixed priority alarm assignment determined for full-power operation. However, experience has shown that this full-power priority is often not applicable for other operating states. In fact, faults may become not relevant in other plant operating states. Consequently, in non full-power operating states, control room staff are required to judge the relative importance of each alarm in real-time and adjust their response to plant conditions.

To address these issues, and other operational needs, Canadian utilities and AECL have jointly developed the CANDU Alarm Message List System (CAMLS) under COG sponsorship. CAMLS permits the dynamic adjustment of alarm priority in response to changes in plant operating state. Simulator evaluations with Operations staff at Darlington and Point Lepreau have demonstrated the operational benefits and practical feasibility of this approach. Dynamic alarm prioritization is being implemented for new AECL plant designs (e.g., CANDU 9 and CANDU 6) and being considered for retrofit alarm improvements (e.g., Pickering and Darlington).

For an annunciation system to be effective, the determination of alarm priorities requires the consistent application of design rules, strategies, and guidelines for classifying and prioritizing alarms with respect to each operational state. Experience has shown this task to be labour intensive, susceptible to human error, and prone to costly rework and on-going maintenance. For example, given a plant with five thousand alarms and 20 operating states, a complete analysis will require in the order of 100,000 prioritization decisions to be performed. Thus the analysis decisions in implementing dynamic prioritization could easily result in several man-years of effort.

To satisfy this, and other alarm system design needs, in 1995 AECL developed an in-house prototype CANDU Alarm Analysis Tool (CAAT) to support CAMLS development. Pilot applications confirmed that CAAT had the potential to reduce the alarm priority determination effort by one half. This experience, while positive, revealed several areas where further improvements in the alarm prioritization method and the supporting design environment were required. These included:

- Consistency - Cross-comparison of the prioritization results of the various CAMLS trial scenarios, undertaken in support of annunciation system tests, revealed problems with the consistency of priority assignment. In several cases, analysts unconsciously biased alarm prioritization based on the perceived importance of an alarm to a specific scenario. As a result, the assigned priority of alarms varied from analyst to analyst. For example, alarms of the same type, (i.e.., Shutdown System trip parameter alarms) were prioritized differently in different scenarios although all trip alarms should have equal importance in trip determination.
- Effort - Assigning and reviewing alarm priorities on a single, alarm-at-a-time, basis was labour intensive. This effort detracted from other potential opportunities for further annunciation improvements (e.g., alarm conditioning).
- Environment - Traditional station support environments for annunciation system information vary from text files to simple non-relational databases. Information technology standardization initiatives of the utilities and AECL required a support tool that would enhance the typical station computing environments. We felt that relational database technology offered much promise. CAAT was initially prototyped in PowerBuilder™, a database front-end tool offered by Sybase Corporation and linked to an IBM DB2™ database. While this product combination was effective, it had little or no support in existing CANDU stations.

Improvement Directions

Pilot experiences, with CAMLS, revealed limitations with the single, alarm-at-time priority assignment approach. Investigation of alternatives led to adoption of five major considerations in our approach:

1. Grouping Alarms of Common Importance: To minimize priority assignment effort, we decided to explore techniques for alarm grouping. Alarms with common importance would be prioritized with a single set of priority assignments applicable to the group.
2. Plant Functions: CANDU plants are divided into individual systems for design purposes. However, Operations staff must monitor and control these systems from a functional perspective in relation to plant operating goals and states. Thus the functional perspective offered an operationally relevant way to develop alarm groups.
3. Function and Alarm Prioritization: An organization of plant functions by importance, with respect to each operating state, would provide a basis for grouping alarms for

prioritization purposes. Priorities for individual alarms would be assigned with respect to the base function priority.

4. Priority Comparison: Development of database tools for assisting in priority comparison among alarms and function groups to highlight inconsistencies.
5. Environment Standardization: Conversion of the alarm tool from the PowerBuilder and DB2 to the Microsoft Access and Oracle environments.

Method Description

Unlike traditional alarm prioritization, the function-based approach considers individual alarms to be indicators (or symptoms) of the health of a specific plant function. As health of a function deteriorates, the function will eventually be lost. Rather than attempt to prioritize the importance of each symptom, we instead focus on prioritizing the importance, to the plant, of the loss of each function. Once functional importance is determined, all associated alarms (i.e., the health indicators of the function), automatically inherit the function's priority assignments.

An initial list of plant functions can be developed by several means. AECL recently undertook a top-down decomposition of CANDU plant functions in support of the CANDU 3/9 development. This hierarchical organization of plant functions led to the definition of 450 functions. A second approach, described below, develops a function list based on the organization of existing station operating and design documentation (e.g., Basic Subject Index (BSI), training and operating manuals etc.,). A third approach, currently being explored, is to identify functions based on the stated purposes for each plant system in station training manuals. Information from all three approaches will be eventually be combined to ensure full functional coverage.

Establishing alarm priority assignments with the second approach involves three steps. Note, examples shown within this document refer to CANDU 6 and Darlington Nuclear Generating Station information.

· Step #1 - Organization and Identification of Plant Functions

In the first step, an organization of plant functions is developed based on existing design and operating documentation to ensure completeness of coverage. We partitioned the plant into 6 major systems (see Table 1). This system partitioning closely reflects the organization of existing CANDU control room panels and design documentation. Others may decide upon a different number and set of major systems, but the partitioning at this stage does not affect the final prioritization results.

Table 1: Major Plant Systems

System	Description
Reactor	Reactor and Heat Transport
Turbine	Steam Generator-Turbine

System	Description
Generation	Generator-Transformer-Switchyard
Safety	Safety Systems
Services	Common Services (Power-Air-HVAC-Water-Communication.)
Control	Control Systems

To ensure consistency with existing control room annunciation, the system designations used in the function-based approach were selected to correspond to the existing system panels and organization of annunciatior tiles. This system correlation is shown in the table below (see Table 2).

Table 2: Control Room Window Tiles

System	Control Room Panel Window Tiles
Safety	PL01 - Containment
Safety	PL02 - Shutdown System No. 2
Safety	PL03 - Emergency Core Cooling (Panel 3A)
Safety	PL03 - Emergency Core Cooling (Panel 3B)
Safety	PL04 - Shutdown System No. 1
Reactor	PL05 - Moderator & Misc. Reactor Systems
Control	PL06 - Reactor Regulating System
Control	PL07X - Annunciation and DCCs
Control	PL07Y - Annunciation and DCCs
Reactor	PL08 - Heat Transport System
Reactor	PL09 - Heat Transport System
Turbine	PL10 - Steam Generator System
Turbine	PL11 - Steam Generator System
Turbine	PL12 - Turbine Generator
Turbine	PL13 - Turbine Generator
Services	PL14 - Common Services
Services	PL15 - Misc. Auxiliary Systems
Generation	PL16 - Electrical Distribution
Generation	PL17 - Electrical Distribution
Generation	PL18 - Class IV Distribution
Generation	PL19 - Generator / Switchyard

Next, thirty-five (35) major subsystems, associated with each of the six major systems, were identified from design and operating documentation (see Table 3). Again, this partitioning was determined based upon a consensus of designer opinion.

In the final phase of this step, station operating manuals were scanned to extract all references to alarms and alarm messages that identified a further set of functions. This preliminary effort resulted in approximately 160 functions associated with the 35 subsystems listed above. For purposes of brevity only functions associated with the 7 reactor subsystems are listed below (see Table 4). This table exists in a MS Access database. The columns include:

1. the System / Subsystem description
2. a function action word (selected from a list of reserved words)
3. the Function_What and Function_Where information are extracted from operating manual names.

Example: The function 'Sample D_2O' (where: Moderator & Auxiliaries) was extracted from the manual 'Moderator D_2O Sampling System'.

Table 3: Major Plant Subsystems

System	Subsystem
Reactor	Reactor
Reactor	Reactor Auxiliaries
Reactor	Moderator & Auxiliaries
Reactor	Heat Transport
Reactor	Heat Transport Auxiliaries
Reactor	Fuel Handling
Reactor	D2O Management
Turbine	Steam Generator Steam
Turbine	Turbine & Auxiliaries
Turbine	Condensate
Turbine	Feedwater
Generation	Generator
Generation	Transformers
Generation	Switchyard
Services	Class I Power
Services	Class II Power
Services	Class III Power
Services	Class IV Power
Services	Emergency Power
Services	Air (Instrument & Breathing)
Services	Gases (H2, N2, etc.) & Lubricates
Services	Heating-Ventilation-Air Conditioning
Services	Cooling Water
Services	Waste Treatment
Services	Water Treatment
Services	Communication
Safety	Containment
Safety	Shutdown System 1
Safety	Shutdown System 2
Safety	Emergency Coolant Injection
Safety	Radiation & Environmental Protection
Safety	Fire Protection
Safety	Site & Asset Security
Control	Supervisory Control
Control	Monitoring

Notes:

1. Only manuals containing alarms contribute to the function list.
2. Functions were classified assuming a single unit station.
3. Some functions (e.g., D_2O Vapour Recovery) are listed several times. These functions occur in several areas of the plant, as identified by the "Function_Where" column and as a result may have different operational priorities. Note, if the operational priorities are judged to be the same, the functions will be collapsed.
4. The operating manual set used in the preliminary scan was incomplete, but was sufficient to meet our pilot needs.

Table 4: Reactor Subsystem Functions

System / Subsystem	Action	Function_What	Function_Where
Reactor - D2O Management	Sample	D2O	Moderator & Auxiliaries
Reactor - D2O Management	Provide	D2O Vapour Recovery	Confinement Room
Reactor - D2O Management	Provide	D2O Vapour Recovery	Fueling Facility Auxiliary Area (West)
Reactor - D2O Management	Provide	D2O Vapour Recovery	Reactor Vault & Fueling Duct
Reactor - D2O Management	Provide	D2O Supply	Unit
Reactor - D2O Management	Provide	Spent Resin Handling	Unit
Reactor - D2O Management	Provide	Resin Deuteration and Dedeuteration	Heat Transport Auxiliaries
Reactor - D2O Management	Provide	Resin Deuteration and Dedeuteration	Moderator & Auxiliaries
Reactor - D2O Management	Provide	D2O Storage and Transfer	Heat Transport Auxiliaries
Reactor - Fuel Handling	Provide	Fueling Machine D2O Auxiliaries	Fuel Handling
Reactor - Fuel Handling	Provide	Cooling and Purification - Irradiated Fuel Bay (IFB)	Fuel Handling
Reactor - Fuel Handling	Provide	New Fuel Handling & Storage	Fuel Handling
Reactor - Fuel Handling	Provide	Irradiated Fuel Handling & Storage	Fuel Handling
Reactor - Fuel Handling	Provide	Fueling Machine Reactor Area Bridge and Carriage	Fuel Handling
Reactor - Fuel Handling	Provide	Fueling Machine Head and Suspension	Fuel Handling
Reactor - Fuel Handling	Provide	Fueling Machine Air Auxiliary	Fuel Handling
Reactor - Heat Transport	Provide	Main Heat Transport Circuit	Heat Transport
Reactor - Heat Transport	Provide	Feeder Pipe Freezing	Heat Transport
Reactor - Heat Transport	Provide	Pressure & Inventory	Heat Transport Auxiliaries
Reactor - Heat Transport Auxiliaries	Provide	Shutdown Cooling	Heat Transport Auxiliaries
Reactor - Heat Transport Auxiliaries	Provide	Purification	Heat Transport Auxiliaries
Reactor - Heat Transport Auxiliaries	Provide	H2 Addition	Heat Transport Auxiliaries
Reactor - Heat Transport Auxiliaries	Provide	D2O Leakage Collection	Heat Transport Auxiliaries
Reactor - Heat Transport Auxiliaries	Provide	D2O Recovery	Heat Transport Auxiliaries
Reactor - Moderator & Auxiliaries	Provide	Main Moderator	Moderator & Auxiliaries
Reactor - Moderator & Auxiliaries	Provide	D2O Collection	Moderator & Auxiliaries
Reactor - Moderator & Auxiliaries	Provide	Liquid Poison	Moderator & Auxiliaries
Reactor - Moderator & Auxiliaries	Provide	Cover Gas	Moderator & Auxiliaries
Reactor - Moderator & Auxiliaries	Provide	Purification	Moderator & Auxiliaries
Reactor - Reactor	Provide	Liquid Zone Control	Reactor
Reactor - Reactor	Provide	Cobalt Adjuster Cooling	Reactor
Reactor - Reactor Auxiliaries	Provide	Annulus Gas	Reactor Auxiliaries
Reactor - Reactor Auxiliaries	Provide	End Shield and End Tank Cooling	Reactor Auxiliaries

Our initial pilot project will base alarm prioritization on this 160 function set, since this approach offers the best potential for reduction in alarm analysis effort. In cases where a function is deemed to be too general in nature to be accurately prioritized, the function set will be expanded to remove any ambiguities.

In a third approach being explored to identify a function list, plant functions are being identified based on the documented purposes of each plant system. This work is currently in progress and is expected to lead to a definition 700 to 900 individual functions.

In the future, we expect to combine the merits of all three function identification approaches to develop a complete set of plant functions for prioritization purposes.

- Step #2 - Prioritization of Plant Functions

Prioritization of each plant function is determined, within CAAT, using a screen similar to the one shown below (see Figure 1). The left hand side of this screen is used to identify the consequences and operator responses, with respect to the loss of each function, for each of the various plant modes (i.e., operating states).

Plant modes are identified on the bottom of this screen and are selected from a drop-down list. Note that several plant modes can share the same priority information. This technique is used to minimize data duplication in situations where the function priority is identical across several modes.

This information is then used by CAAT to automatically calculate the function priority value for each plant mode.

Prioritization of plant functions is expected to be common to all CANDU plants. Once performed the results can be applied to any plant.

- Step #3 - Assignment of Individual Alarm Priorities

Alarm assignment to a function is shown on the right hand side of the screen (see Figure 1). It is expected that alarms will be initially assigned to a functional group by matching the alarm BSI number to the BSI of the subsystem which corresponds to this function. Since the alarm set and BSI list is not identical between all plants, each plant will be required to match their alarm set to the list of plant functions. This should not be a large effort.

Within CAAT we also have the ability to enforce alarm analysis rules. One such rule, that we are considering, is that an alarm can only be assigned to one function. In the situation where an alarm could potentially be associated to more than one function, it is thought that a second alarm should be created. This rule is being considered to ensure that the alarm message text would reflect the challenge to the health of the challenged function. The downside of this rule is that, in some situations, two messages may be generated.

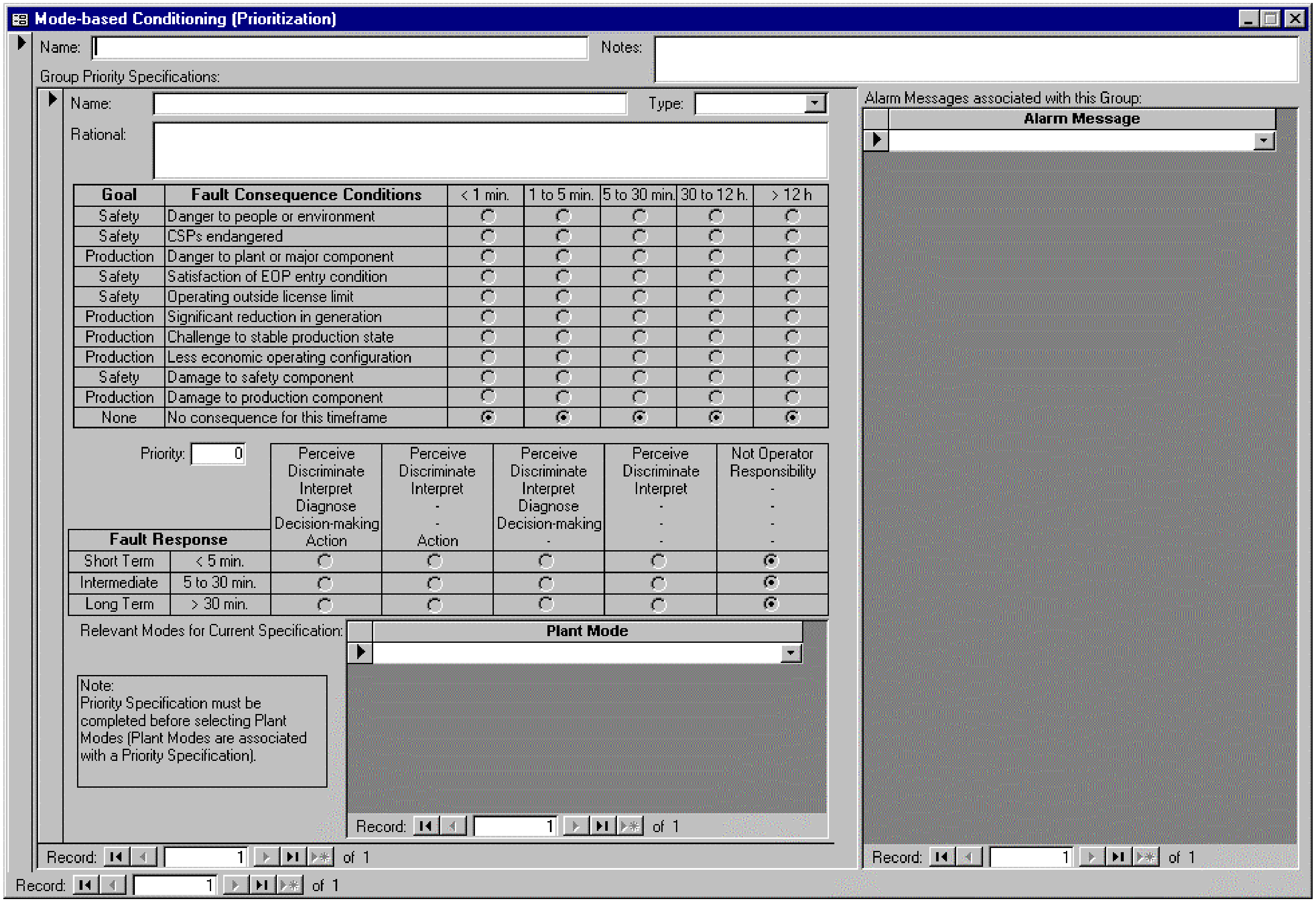

Figure 1: Function Prioritization Screen

Another benefit of relation database technology is that a report can be generated of all unassigned alarms. In this situation, either the alarm was overlooked by the analyst, or a function decomposition was incomplete. The use of database technology should lead to a more consistent and complete annunciation system.

Experience with Pilot Application

While this new approach has not been verified in station trials, we intend to conduct a pilot application in 1998-99 as a comparison with past alarm analysis results. The pilot application will involve operationally evaluating the suitability of alarm priority assignments for a number of predefined scenarios in a simulator environment. The initial alarm priority assignments will be performed using an enhanced version of CAAT based on a Microsoft Access database. The new function-based priority assignments will then be loaded into CAMLS for testing the suitability of the alarm priority assignments in representative operational scenarios. The results will be compared to those obtained from previous CAMLS station trials.

Benefits

We expect the function-based alarm prioritization approach to offer several benefits over former alarm prioritization approaches, for example:

1. A substantial reduction in alarm analysis and maintenance effort by a factor of 10 to 50 since alarm priorities are determined on a group basis rather than individually.
2. Inconsistencies in alarm priority assignments among analysts should be substantially reduced over former practices since analysts will work from a common function prioritization base.
3. The annunciation model supported by this function-based approach should provide a more consistent representation of plant state since it more closely matches the importance determination reasoning practiced by station Operations staff.
4. The function-based approach and results should be applicable to all existing and future CANDU stations in that a large number of the plant functions are generic.
5. An overall cost saving for new and retrofit plant designs, based on less initial analytical effort and subsequent rework.
6. The function-based approach, combined with current database technology, should provide system designers with a better overview of the current plant alarm coverage.

We also expect this function-based approach to establish the framework for introducing next generation control room displays based on function and health of functions.

Conclusions

An improved approach to alarm prioritization has been developed. This method is based on a functional organization of plant alarms and employs the same alarm importance determination reasoning as currently practiced by station Operations staff. A trial application is expected to achieve: operationally consistent priority assignments among related alarms, the promise of substantial reduction in alarm priority analysis effort for new and retrofit plant designs, and an overall cost saving.

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