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Evaluation of an Alarm System Using Signal Detection Theory(SDT)

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Abstract

When the process disturbance of nuclear power plant occurred, the operator should ensure plant safety, economy and identify the causes of disturbance. To accomplish these goals, operator should process a large amounts of information. Among these, alarms would be often in the operator's first indication of a plant state change or disturbance. To support limited information processing capability of operator, considerable works are under way to develop advanced alarm processing systems and to evaluate it. However, conventional evaluation method could provide just evaluation results but the design alternatives to enhance alarm system performance. To overcome problems associated with conventional evaluation methods of alarm system, signal detection theory(SDT) was introduced, and it was possible conclude that SDT could not only evaluate system but also suggest design alternatives for performance enhancement.

I. Introduction

The operator of a nuclear power plant(NPP) has a certain goals in order to monitor and maintain control of a complex process. Faced with a process disturbance, these goals are: 1) to ensure plant safety, 2) to diagnose the disturbance, and 3) to ensure plant economy.[1] To attain these goals successfully, a large amounts of information that have various degrees of importance and different formats should be processed by operator. Among these information, the alarms are very critical, since they would be often in the operator's first indication of a plant state change or disturbance. However, diagnosis of disturbances and on-line planning of remedial actions are very difficult tasks for operator because of their limited resources of time and information processing capability.[2] To reduce operator's workload, therefore, considerable works are under way to develop advanced alarm processing systems. In this situation, system designers have been faced with the problems of: 1) how to design the system to meet the functional requirements of safety and economy and 2) how to evaluate and/or validate the efficiency of the proposed design. Especially, appropriate evaluation methods that could be used in the early stage of system design are very needed for attainment of functional requirements and improvement of efficiency. However, the evaluation methods that were conventionally used for advanced alarm system have several problems, such as a lack of objectivity due to expert's judgment. Furthermore, most of them could not provide alternatives for enhancing performance with system designer. That is, these evaluation methods could provide not the design alternatives for enhancement of alarm system performance, but just evaluation results.

To overcome problems associated with conventional evaluation methods of alarm system, signal detection theory(SDT) was introduced in this paper. The evaluation results represented by A′ score could identify the performance of alarm system, such as filtering capability or sensitivity, and could suggest alternatives for enhancement of alarm system performance. To verify the feasibility of SDT for alarm system evaluation, this method was applied to dynamic alarm console(DAC) that is a prototype alarm processing system developed in KAIST. In addition, the performance of DAC were evaluated using LOCA alarms that obtained from full scope NPP simulator.

II. Backgrounds

II.1 Signal Detection Theory

Information processing of human operator begins with the detection of some environmental event. This detection could be modeled within the framework of signal detection theory(SDT).[3] To use SDT, following conditions should be satisfied.

- There are two discrete states of the world(called signal and noise) that cannot easily be discriminated.
- These state of world must be detected and processed by the human operator.
- Two kinds of response must be produced, such as "yes" or "no", after information processing.

The combination of two states of the world and two kinds of response produce the 2×2 matrix shown in Fig.[1], and generated four classes of joint events which are called hits, misses, false alarms(FAs) and correct rejections(CRs). Here, hits mean that the operator considers right environmental event as right event , i.e., signal. Similarly, misses mean that the operator considers right environmental event as wrong event, i.e., noise. Therefore, it is apparent that perfect performance is possible when no misses or false alarms occurred. In SDT, these four classes of joint events could be represented using probability, as like below.

- P(hit) + P(miss) = 1.0, P(hit) = number of hits/total number of hits and misses.
- P(FA) + P(CR) = 1.0, P(FA) = number of FAs/total number of CRs and FAs.

Using these probabilities, three kinds of non-parametric measure of human performance, such as A′, d′ and β, could be calculated. Among these measures, A′ score could represent the information processing performance of human, and can be calculated using the following equation.

$$A' = 1.0 - 0.25\cdot\left\{\frac{P(FA)}{P(Hit)} + \frac{[1.0 - P(Hit)]}{[1.0 - P(FA)]}\right\}$$

Where, A′ score of 1.0 and 0.0 indicates perfect and worst performance of human, respectively.

II.2 Dynamic Alarm Console

The Dynamic Alarm Console(DAC) is a prototype of CRT-based alarm filtering and prioritizing system developed in KAIST. The DAC provides the operator with filtered and dynamically prioritized alarms. Dynamic prioritization is achieved by going through the system- and mode-oriented prioritization. System-oriented prioritization aims to identify the importance of the alarm within the system to which the alarm belongs. To assign larger value to higher system-oriented priority, system-oriented importance function, $S(x)$, is defined. Where, x is the individual alarms and $S_p(x)$ is system-oriented priority.

$$S(x) = 19.0 - S_p(x)$$

Mode-oriented prioritization aims to assign the importance of the system to which the alarm belongs in current operating mode, because it's importance is dynamically changed according to operating modes. To identify mode-oriented priority, mode-oriented weight function, $M_w(x)$, was introduced.

$$M_w(x) = \begin{cases} 1.0 & \textit{if } x \in \textit{safety or indispensable systems} \\ 0.55 & \textit{if } x \in \textit{support systems} \end{cases}$$

After completing system- and mode-oriented prioritization, the final prioritization function, $F_p(x)$, was used as follows.

$$F_p(x) = S(x) \cdot M_w(x)$$

- If $F_p \geq 16$, then assign priority 1(immediate action-required alarm)
- If $8.8 \leq F_p \leq 16$, then assign priority 2(warning alarm)
- If $F_p \leq 8.8$, then assign priority 3(inconsiderable alarm)

III. Development Strategy of Alarm System Evaluation Method Using SDT

As mentioned before, information processing performance of human could be modeled using SDT, when three kinds of conditions are satisfied. In SDT, human was considered as information processor that consisted of three steps; detection, processing and response. Fig.[2] shows this paradigm. In Fig.[2], some information from environment was leaked, and some noise was affected because of limited capability or sensitivity of information processor, i.e., human. Therefore, measures calculated from SDT could represent the performance of information processor.

In the point of information processing, it is worth comparing between SDT paradigm and schematic architecture of alarm processing system which is represented in Fig.[3]. This shows that alarm processing system consists of three parts; input, processing and output. Furthermore, some right information(i.e., important alarms) from NPP could be filtered out, or some wrong information(i.e., nuisance alarms) could be provided with operator(i.e., did not filtered out), due to it's limitation of processing capability or sensitivity. Besides, essential alarms to identify plant disturbance did not clearly distinguished from input alarms because the essentiality are dynamically varied according to operation modes, and two class of alarms, such as essential or not, were generated after alarm processing.

From these observations, it is natural to use SDT for the evaluation of alarm system performance, and it could be reliable to use non-parametric measures of SDT for evaluation, since SDT paradigm and the architecture of alarm processing system are very similar.

To gain P(hit) and P(FA) that are needed to calculate A' score, the key alarm sets that could distinguish the right or wrong outcomes (i.e., "yes" or "no") from the processed alarms should be classified. After the classification of key alarm sets, the number of hits, misses, FAs and CRs can be determined according to each priority level. Fig.[4] shows an example of settlement strategy for priority 1 alarms. Here, the number of hits was determined from the number of common alarms between predetermined key alarm sets and priority 1 alarms, and the number of FAs could be obtained by subtracting the number of hits from the total number of priority 1 alarms. The number of misses and CRs could be determined similarly.

IV. Results

The selected key alarm sets that can specify LOCA accident are shown in Table [1].[4] Using these key alarms, A′ scores and the number of alarms that was processed by DAC in each level of priority are shown in Table [2]. A′ scores of priority 4 were ignored in this table because of it's importance(i.e., suppressed alarms), and the meaning of "E" and "N" were the number of "essential" and "nuisance" alarms included in each priority, respectively.

From these classifications of processed alarms, the A′ scores of each priority level can be determined with respect to time, as shown in Fig.[5]. As can be seen in Fig.[5], the A′ scores of priority 1 are increased rapidly when NPP tripped and increased gradually during NPP was undergoing LOCA. In the case of priority 2, the overall trend of A′ scores decreased, although the rapid increase of A′ scores occurred when NPP tripped. In the case of priority 3, however, the A′ scores decreased rapidly when NPP tripped, and retained about 0.55 during LOCA accident. From these observations, it was possible to conclude that DAC had reasonable processing performance for priority 1 alarms, because A′ score that was contiguous to 1.0 means high performance of system, as mentioned before. Furthermore, it was reasonable to conclude that DAC could support the operator with diagnosis capability of disturbance or on-line planning of remedial action, since the A′ scores of priority 1 alarms(i.e., immediate action-required alarms) increased when these of priority 2 alarms(i.e., warning alarms) decreased. In other word, since the priority 1 alarms were essential to identification of disturbance, the increase of A′ scores was more helpful to the on-line planning of remedial action of operator, although the processing performance for priority 2 decreased, because they were classified with priority 1 alarms during LOCA accident.

The A′ scores could optimize the processing logic of specific alarm processing system, since these A′ scores should be affected by processed alarms, and these alarms should be classified using some kinds of processing logic, such as filtering logic or prioritization rules. For example, Fig.[6] shows average A′ scores that were affected by prioritization function, such as $F_p(x)$, $S(x)$ and $M_w(x)$. If the criteria of each prioritization function were changed, then the average A′ scores should have different trends or values. Therefore, it was possible to conclude that the most appropriate criteria of each prioritization function which could generate high A′ scores can be settled by comparing A′ score. Similarly, another measure of SDT, such as d′ and β, can be used both alarm system evaluation and optimization.

V. Conclusions

A′ score based on signal detection theory has been introduced which is capable of quantitatively evaluating and presenting alternatives for enhancement of alarm system performance, since the paradigm of SDT and the architecture of alarm processing system were very similar. These A′ scores were calculated to evaluate the performance of DAC during the LOCA scenario, and the results indicated that: 1) A′ score could be represent performance of alarm processing system and 2) the alternatives for performance enhancement could be suggested by A′ scores.

References

1. "Man-Machine Interface Systems", EPRI URD, Vol. II, Ch. 10, 1991.
2. Morten Lind, "Modeling Goals and Functions of Complex Industrial Plants", Applied Artificial Intelligence, Vol. 8, pp 259-283, 1994.
3. C. D. Wickens, "Engineering Psychology and Human Performance", University of Illinois at Champaign-Urbana, 1984.
4. "Emergency Operating Procedure of Young-Gwang Unit 1, 2", KEPCO, 1990.

Table [1]. Predetermined key alarm sets for LOCA accident.

Related System or component	Key Alarms
Containment	• 1E RAD HIGH ALARM • NON-1E RAD HIGH ALARM • 1E RAD HI MONITOR WARN • NON-1E RAD MONITOR WARN • CTMT PRESS HI-1,2,3 ALERT • CTMT PRESS HI SI RCT TRIP • CONTAINMENT PHASE B ISO ACTUATED • CONTAINMENT SPRAY ACTUACTED • CTMT SUMP A,B LEVEL HI/HI-HI
Accumulate & Refuel Water Storage Tank	• ACCUM TK A,B,C LEVEL HIGH/LOW • ACCUM TK PRESS HIGH/LOW • REFUEL WTR STOR TK LEVEL LOW(NARR RNG) • REFUEL WTR STO TK LVL LO-LO
Pressurizer	• PZR LEVEL LOW • PZR PRESS LOW • PZR PRESS LOW ALERT • PZR CONT LEVEL LOW DEVIATION • PZR PRESSURE LOW/BACKUP HTR ON • PZR CONT LEVEL LOW HEATERS OFF • PZR LO PRESS & P7 RCT TRIP • PZR PRESS SI
Others	• OVER TEMP DT RCT TRIP • MAIN FW CONTROL V/V BLOCKED • MSIV TRIPPED • LOOP 1,2,3 RC LO FLOW ALERT • LOOP 1,2,3 RTD BYPASS FLOW LOW • SPRAY ADT TANK LEVEL LO/LO-LO

Table [2]. The number of alarms in each priority that was processed by DAC, during first 4 minutes after Rx trip.

Times after Rx tripped	Priority 1			Priority 2			Priority 3			Priority 4		
	E	N	A′	E	N	A′	E	N	A′	E	N	A′
Rx trip	5	3	0.2181	3	2	0.3303	1	0	0.7692	5	2	-
1 min.	6	7	0.6743	3	3	0.6296	1	0	0.7667	6	15	-
2 min.	7	7	0.7009	3	3	0.6092	3	5	0.4506	6	13	-
3 min.	7	7	0.7009	3	3	0.6092	3	5	0.4506	6	13	-
4 min.	7	8	0.6550	3	3	0.6092	3	4	0.5340	6	13	-

		State of the world	
		Signal	Noise
Response	Yes	Hits	FAs
	No	Misse	CRs

Fig.[1] The four outcomes of SDT.

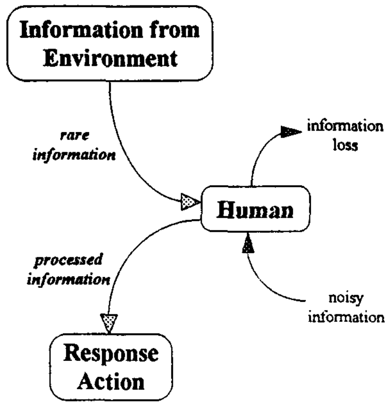

Fig.[2] Information processing paradigm in SDT.

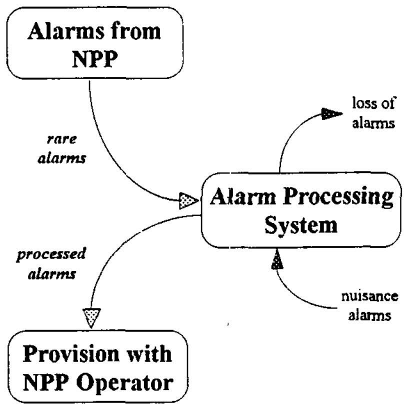

Fig.[3] Schematic architecture of alarm processing system.

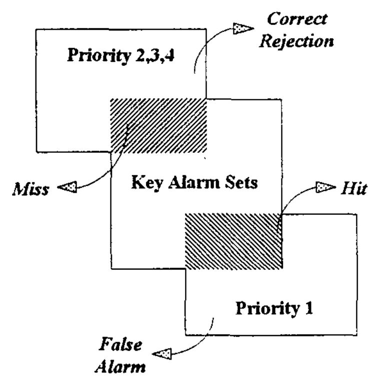

Fig.[4] Outcomes settlement strategy(priority 1).

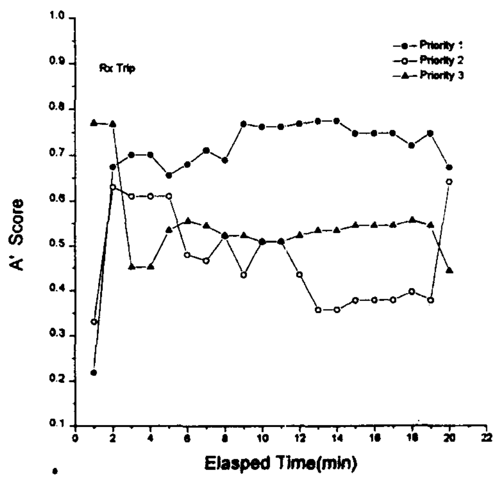

Fig.[5] The evaluation results of DAC using A' scores.

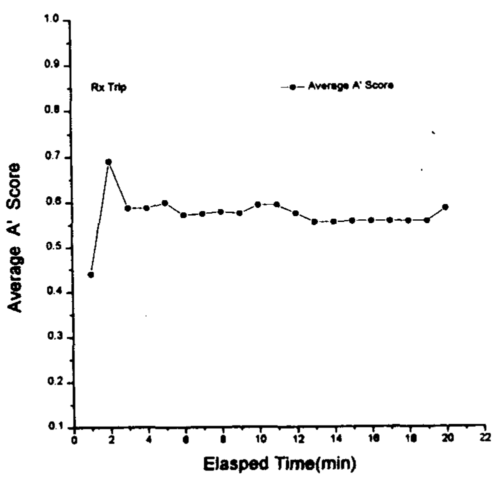

Fig.[6] Average A' score of DAC with respect to time.