Determining Cue Presentation Time for Diagnosis Error Probability of THERP-like Methods using Confidence Interval of Performance Time

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1. Introduction

Human reliability has been assessed for predicting and managing potential risks in complex systems [1]. Diverse HRA methods have been developed, which evaluated human errors including cognition and execution failures with considerations of their situational factors and predicted the human error probabilities (HEPs) of the human events.

Among various situational factors, time has been recognized as an important factor in predicting human error [2]. Some tasks performed by operators do not have sufficient time depending on the accident situations; hence, many methods such as THERP (Technique for Human Error Rate Prediction), ASEP (Accident Sequence Evaluation Program), K-HRA, and HuRECA (Human Reliability Evaluator for Control Room Actions) have closely linked the performance time to possible failures in diagnosis [3-6]. For example, the THERP method employs a time-reliability curve as shown in Fig. 1 for estimating the diagnosis error probability (DEP) of human operators.

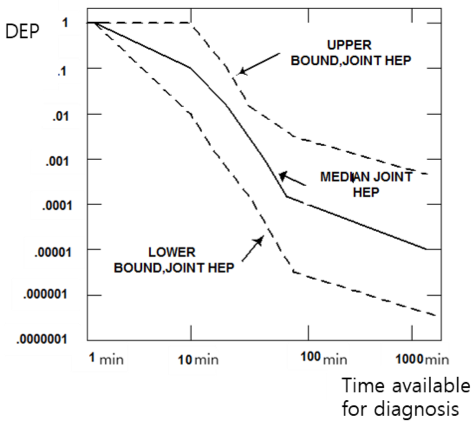

Fig. 1. Time-reliability curve of the THERP method [3]

In the process of predicting the DEP, it is important to select a critical cue and calculate the cue recognition time for a given event. Fig. 2 describes the examples of the significant period and time points regarding the performance time for a human failure event (HFE). The K-HRA method, for example, employs the time available for diagnosis (TAD) for the DEP. In this situation, the identification of the cue presentation time is critical to the TAD and the DEP.

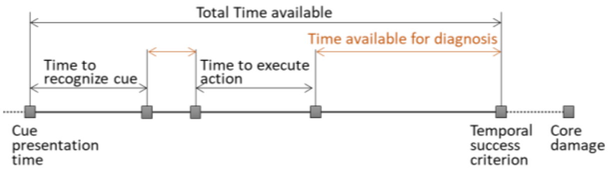

Fig. 2. The time information of an HFE

However, when an operator has two or more cues required for the task performance, it is challenging for the analyst to determine the critical cue. Table I shows the examples of cue presentation times for the feed-and-bleed operation in various situations, which were derived using thermal-hydraulic analyses. In the case of the APR1400 plant, the depletion of steam generator (SG) or the first open of the spring-loaded pilot valve (SLPV) can be regarded as the main cues of the feed-and-bleed operations. However, since the presentation times of the two cues greatly vary depending on the accident situations, the DEPs can be changed based on the selection of the critical cues. The last two rows of Table I shows how differently the DEPs were estimated by the K-HRA method.

Although the critical cue selection is very important to HEP calculation, the scientific criterion for this has not been developed so far. In this paper, we propose a technique of selecting a critical cue and calculating its

Table I. Different cue times of feed-and-bleed (F&B) operation and their DEPs

Accident scenario		A	B	C	D
Cue presentation time and available time (unit: min)	Tsg	205	56	38	25
	Tsl	268	452	43	30
	Ta	293	497	78	40
TAD (unit: min)	TAD1 (=Ta-Tsg-Drec-Dexe)	86	439	38	13
	TAD2 (=Ta-Tsl-Drec-Dexe)	23	43	33	8
DEP	*f*(TAD1)	6.55E-04	2.04E-04	3.87E-03	1.11E-01
	f(TAD2)	2.37E-02	2.56E-03	6.18E-03	2.02E-01

* Ta: total time available; Tsg: SG exhaustion time; Tsl: SLPV first opening time; Drec: duration for recognition; Dexe: duration for execution; TAD: time available for diagnosis

presentation time by grouping several cues based on the confidence intervals for human performance time.

2. Related Work

For realistically assessing the time-related reliability, several reports summarized good guidelines of time analysis. For example, the guidelines for the Petro-HRA method and fire HRA method emphasized that visualization of the timeline supports to understand the interaction between human operator's behaviors, accident evolution, and instrumentation information and to extract significant time information in the HFE [7,8].

However, there have been few studies for the determination of critical cues. Recently, Kim et al. presented an algorithm to evaluate a time-related HEP based on the time information of instrumentation cues and procedure cues [2]. That study proposed a criterion for deciding time parameters that can be used for the EMBRACE (EMpirical data-Based crew Reliability Assessment and Cognitive Error analysis) [9], HCR/ORE (Human Cognitive Reliability/ Operator Reliability Experiments) [10], and SPAR-H (Standardized Plant Analysis Risk - Human Reliability Analysis) [11]. Fig. 3 depicts the proposed algorithm.

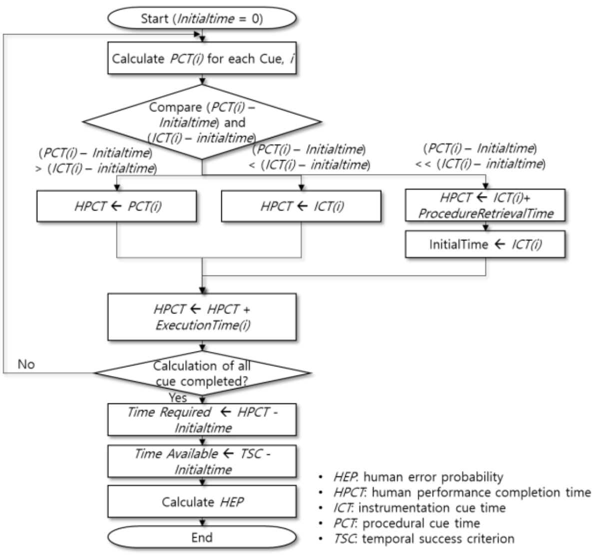

Fig. 3 The algorithm calculating a time-related reliability [2]

The THERP method has a different perspective on the time with other methods such as EMBRACE, HCR/ORE, and SPAR-H. While the other methods estimate the time sufficiency of the given event based on the ratio between the time available and time required, the THERP method focuses on the relation between diagnosis errors and the time margin and attempts to predict a DEP using the TAD. This paper thus proposes a technique for calculating a critical cue presentation time that can be implemented into the THERP-like methods including K-HRA and HuRECA by modifying the algorithm of [2].

3. Proposed Technique

3.1 Definition

The significant concepts regarding human performance time for explaining the proposed technique are defined as follows:

- Cue: information that can evidently remind the operator of the need for major actions of a human event of interest (a cue can be generated from procedures or instrumentations.)
- Cue presentation time: the time that the cue is presented to a crew
- Cue recognition time: the time when the crew perceives any need to respond to the presented cue
- Cue activation period: the period in which the operator is actively aware of the need for major actions based on a specific cue
- The end time of cue activation: the end point of the cue activation (usually, the sum of the cue presentation time and the cue activation period)
- Critical cue: the first cue whose activation period substantially contains the recognition time of the last cue

Fig. 4 shows the examples explaining the above definitions.

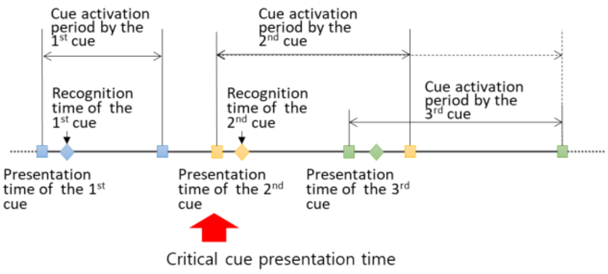

Fig. 4 The time frame exemplifying the times and periods defined for this study

3.2 Assumption

The following assumptions were considered for determining the critical cue. First, operators can initiate significant action relevant to an HFE when any cue presents. Second, the operators follow procedures to cope with ongoing situations. Third, all cues substantially remind operators of the need for major actions. Fourth, there exists a cue activation period during which the operators can continuously think of the need for specific responsive actions. After the period, it is assumed that the operator is no longer

Table II. Critical cue determined by the proposed technique and the resultant DEPs

Accident scenario	A	B	C	D
Procedure step addressing SG exhaustion	SFSC	SFSC	SFSC	ORP, 7th step
Procedure step addressing SLPV open	F&B operation procedure, 8th step			
Median procedure progression time between two cues	23	23	23	9
Cue activation period	40.25	40.25	40.25	15.75
The end time of cue activation	245.25	96.25	78.25	40.75
Tsl + Drec	269	453	44	31
Critical cue time	Tsl	Tsl	Tsg	Tsg
TAD	23	43	38	13
DEP	2.37E-02	2.56E-03	3.87E-03	1.11E-01

considering the previous cue. Lastly, if the operator is proceeding with the procedural contents based on any cue, it is considered that the cue is actively recognized. In other words, when the operator cannot proceed a procedural step due to mismatch between a plant parameter and procedure conditions, the activation period is also terminated. The cue activation period is determined by the time to follow the sentences in the procedural steps relevant to the cue.

3.3 Determination Process

Based on the above assumptions and definitions, the critical cue time is determined and the DEP is calculated with the following sequence.

(1) Define the cues addressing the need for the major actions achieving the goals of a human event and regard them as the candidates of the critical cue
(2) Calculate the presentation time for each cue
(3) Identify the relevant procedure steps and sentences instructing the verification of each cue
(4) For each cue, estimate the 95 percentile of the time to follow the procedural steps between two neighboring cues and assert the 95 percentile of the time as the cue activation period
(5) From the initial cue of the selected event, check whether the end time of activation for each cue is higher than the recognition time of subsequent cue
(6) If the former is higher than the latter in (5), set the end time of current cue activation to the end time of subsequent cue activation, remove the subsequent cue from the candidates of the critical cue, and repeat (5) for the current cue and the cue after the second
(7) If the former is not higher than the latter in (5), remove the current cue from the candidates of the critical cue, and repeat (5) for the subsequent cue and the cue after the second
(8) After (5) to (7), determine the finally remained cue as the critical cue and calculate the TAD and the DEP for the given event.

For estimating the 95 percentile of the time to follow from a specific procedural step to another, it is possible to statistically analyze the data obtained from simulation records, cognitive or physical walk-throughs, or interviews with the experts. For example, the HCR/ORE experiment and HuREX data for APR1400 showed that the human performance time in nuclear control rooms can be described with the log-normal distribution [9,10]. From the HCR/ORE, the standard deviation of the log of the distribution was estimated to be 0.57 for the conventional control room of general pressurized water reactors [10]. Kim et al. also estimated the standard deviation of the log-normal distribution for the APR1400 plant operators as 0.3403 from the HuREX data [9].

When a human performance time follows a sort of log-normal distribution, the 95 percentile of confidence interval can be calculated from the median performance time with the following equation [9]:

$$Time_{95\%} = Time_{50\%} * \exp(1.645 * \sigma). \quad (1)$$

Here, $Time_{95\%}$ is the 95 percentile of a particular performance time, $Time_{50\%}$ is the median of the performance time, and σ is the standard deviation of the logarithmic values.

4. Application Example

To test the feasibility of the proposed technique, we analyze the four events described in Table I. The σ was assumed to be 0.3403; the exp(1.645* σ) was hence calculated to be 1.75. We also assumed that Drec and Dexe were 1 min. The performance period of each step was supposed to be 1 min while the completion duration of the safety function status check (SFSC) procedure was assumed to be 15 min.

Table II summarizes the results of the application examples. Although the verification of SLPV open is instructed in the same procedural step, the steps addressing SG exhaustion were different along with accident conditions. The procedure progression times were also different according to the accident conditions. The presentation times of the critical cues for the human events under conditions, A and B, were determined to be Tsl because there were sufficient gaps between Tsg and Tsl. However, the intervals between Tsg and Tsl under situation C and D were not significant compared to the procedure progression; the critical cue presentation times for C and D were Tsg.

5. Discussion and Conclusion

In this study, we proposed a technique selecting the critical cue for the methods of predicting DEP using the THERP's time reliability curve. This technique allows the HRA practitioners to objectively select the presentation time of the critical cue using the actual procedure progression time based on the confidence interval. It is expected that the use of this technique is beneficial to reduce unnecessary subjectivity of analyses and minimize analyst-to-analyst variabilities and inter-analyst variabilities.

For accurately assessing DEPs, practitioners need to understand the meaning of the time reliability curve in THERP-like methods. The HCR/ORE or EMBRACE method evaluates how sufficient the operator's performance time is compared to a given total time available. On the other hand, THERP evaluates the amount of the time available that the operator can use to figure out how to cope with the situation. Therefore, it is important to properly extract the time information required by each method for producing a meaningful DEP.

Like other processes in HRA, the qualitative analyses including cue identification and characterization are very important to the DEP quantification. For example of the analyses, the timeline of human events should be investigated in detail [7,8]. In addition, the time information should be estimated from credible data sources. With a clear understanding of performance time, we believe that the risks of systems could be predicted realistically.

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