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A Comparison of Human Reliability Analysis Methods for Post-Initiators

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1. Introduction

Human reliability analysis (HRA) is a method for evaluating human errors and providing human error probabilities (HEPs) for the application of probabilistic safety assessment (PSA) [1-3]. The main purpose of HRA in the context of the PSA is to identify, analyze and quantify all human failure events (HFEs) represented in the logic structure of the PSA, before and during the accident, which contributes to plant risk as defined in the PSA. HRA has been performed in a variety of complex systems such as nuclear power plants (NPPs), military systems, aircraft and chemical plants.

The field of HRA has been considered as one of the areas with high uncertainty in the PSA because it has several challenges regardless of differences in HRA methods [4,5]. These are the representative weaknesses in current HRAs; 1) data scarcity for predicting human behavior, 2) limited representation of the cognitive aspects of human performance, and 3) significant differences in HRA results from different HRA analysts who have used the same method.

For this reason, there has not been a universally accepted or unanimous HRA method for the estimation of HEPs, although many HRA methods have been developed for overcoming these challenges as mentioned above. Up to date, only a few HRA methods have been practically applied in different industries, plants, and units. The use of different HRA methods may rely on; 1) different assumptions, 2) human performance frameworks, 3) quantification algorithms, and data [6].

Up to date, a few comparison studies were conducted to select and apply the most suitable HRA method for the corresponding fields. However, these studies do not contain why the results of HRA are different in the aspect of quantification process among the HRA methods. Therefore, there is need not only to compare the human error probabilities on different HRA methods, but also to understand how the quantification methods and HEPs are different, based on frequently used HRA methods.

This study aims to compare human reliability analysis methods, in terms of quantification process. First, four HRA methods, i.e., EPRI (Electric Power Research Institute) method, ASEP (Accident Sequence Evaluation Program), SPAR-H (Standard Plant Analysis Risk HRA), and K-HRA (Korean standard HRA), are selected for the comparison. These HRA methods are typically used, or based on the widely used one. Second, 7 post-initiators which have representative HRA conditions for OPR1000 type of NPPs in Korea are considered and analyzed in this study. Post-initiator means a HFE that includes operator’s errors in response to a disturbance after the initiating event. In addition, recovery factors and dependencies between HFEs are not included in this study. Lastly, an investigation of HRA results was carried out to verify the differences of HRA methods.

2. Selected HRA methods

2.1. EPRI method

This method is a combination of three HRA methods, i.e., CBDT (Cause-Based Decision Tree), HCR (Human Cognitive Reliability) and THERP (Technique for Human Error Rate Prediction). In the case of diagnosis part, CBDT and HCR respectively calculate diagnosis HEPs. Then, a higher value is selected as a final diagnosis HEP. On the other hand, THERP estimates execution HEPs in this method.

2.1.1. HCR method

HCR [7] is developed by EPRI and estimates non-response probabilities for post-initiators. It uses time response curve for the diagnosis HEPs, which are based on the simulator data from the main control room of full-scale NPP.

2.1.2. CBDT method

CBDT [7] was developed by EPRI for the purpose of supplementing HCR when HCR produces very low probabilities and extrapolation of time response curve is extremely optimistic.

This method identifies specific causes of human error and evaluates the impact of performance shaping factors (PSFs) for post-initiators. PSF is any factor that influences human performance, such as experience, stress, and task complexity. This approach assumes two failure modes, and each one includes four error mechanisms, which are observed in the experiments. Each error mechanism estimates error probability using a decision tree. Finally, HEP of CBDT is calculated by the sum of all the error probabilities from the decision trees of the error mechanisms.

2.1.3. THERP method

THERP [1] is a comprehensive HRA approach developed for U.S. Nuclear Regulatory Commission (U.S. NRC). THERP was applied in WASH-1400 which is the first PSA report and may be used more than any other HRA methods across a variety of industries.

THERP adopts decomposition approach for execution portion of post-initiators. It breaks a task into sub-tasks, then assigns a basic HEP for each sub-task to reflect the potential impact of PSFs. Basic HEP is estimated by THERP data, then the effect of PSFs is considered as multipliers for adjusting basic HEP. Lastly, final execution HEP is calculated by summation of all the estimated HEPs of sub-tasks.

2.2. ASEP method

ASEP [8] is a simplified version of THERP. It provides a fixed set of PSFs and it is made to enable HRA practitioners at a reasonable cost, with minimum support and guidance from HRA experts.

ASEP estimates diagnosis HEP by using time/reliability correlation curve suggested in THERP. In the case of execution portion, ASEP decomposes an operator task into sub-tasks, as same as THERP approach. Then, it selects execution HEP of each sub-task on corresponding stress level and task type. Even though these are also based on THERP, the HEPs are determined in an easier way according to the PSF conditions. Finally, execution HEP is estimated by the sum of all the HEPs of sub-tasks.

2.3. SPAR-H method

SPAR-H [9] is a quantification technique for addressing pre- and post- initiators, and developed for U.S. NRC. As an easy-to-use method, SPAR-H has been widely used in both industry and regulators in its intended area of use (i.e., NPPs in the U.S.), as well as in other industries.

SPAR-H uses the same approach for calculating diagnosis and execution HEPs. It assumes fixed nominal HEPs for diagnosis (i.e., 1.0E-2) and execution (i.e., 1.0E-3), then multiplies the PSF influences associated with the value of corresponding PSF levels. SPAR-H considers a fixed set of 8 PSFs, such as available time, stress/stressors, experience and training, complexity, ergonomics, procedures, fitness for duty, and work process.

2.4. K-HRA method

K-HRA [10] is a standardized method based on ASEP and THERP but developed by Korea Atomic Energy Research Institute (KAERI). It includes structured and specified analysis procedure, quantification rules and criteria for minimizing the deviation of HRA results caused by different analysts, based on consensus between HRA user organizations.

For diagnosis HEPs, K-HRA follows general approach, which is introduced at the beginning of this section. K-HRA estimates basic HEP by THERP curve as same as ASEP, then considers PSF multipliers. These five are the K-HRA PSFs considered in diagnosis portion; primary task, human-system interface (HSI), procedure level, experience/training, and decision burden, and each one also has corresponding PSF levels and multipliers.

Quantification approach for execution HEP in K-HRA is considerably similar with ASEP. It also selects decomposition method as same as THERP and ASEP, and estimates execution HEP of sub-tasks on task type and stress level. Finally, execution HEP is also estimated by the sum of all the HEPs of sub-tasks.

3. Comparison of HRA methods

This study considered 7 post-initiators for OPR1000 type NPPs. Then, these are analyzed by applying four HRA methods. Finally, comparison of HEPs on the selected methods was conducted, focusing on investigating quantification differences for the diagnosis, execution, and final HEPs.

3.1. HFE selection

This study defined different HRA conditions according to the time available for task and PSF influences. First, time available for a task means given time for operators to perform diagnosis and execution before plant states become unacceptable. It is classified into four groups, i.e., expansive time, nominal time, urgent time, and extremely urgent time, based on time criteria defined in THERP and K-HRA. Second, each group is subdivided into two parts, according to whether PSF influences are favorable or not. When the PSF influences are favorable, most of PSFs have positive effects, i.e., high experience, low stress level, and low task complexity. In contrast, unfavorable PSF influences generally contain negatively evaluated PSF levels.

Totally, 7 post-initiators which are representatives for each HRA condition are selected for comparing four HRA methods. Table I represents HRA conditions for 7 HFEs depending on the available time for task and PSF influence. In the case of HFE 1, 3 and 5, these are the representatives which have favorable PSF influences on different time groups. On the other hand, HFE 2, 4, 6 and 7 represent unfavorable PSF conditions with different ranges of available time for the task. In addition, a HFE with extremely urgent time and favorable PSF influences is not treated, because this condition is rare, and extremely urgent time makes highly negative PSF effects.

For the comparison, all the HFEs are separated into two groups, i.e., 1) Group with favorable PSF influences (HFE 1, 3 and 5), and 2) Group with unfavorable PSF influences (HFE 2, 4, 6 and 7), because comparing all the HFEs at the same time makes it difficult to distinguish the effect of time available and PSF influences.

3.2. Comparison of diagnosis HEPs

Diagnosis portions for 7 post-initiators are analyzed on 1) CBDT/HCR, 2) ASEP, 3) SPAR-H, and 4) K-HRA.

Table I: HRA conditions of seven HFEs on available time for task and PSF influence

Available time for task	PSF influence	HFE No.	Time data				Available time for task	PSFs				
			T_{sw}	$T_{1/2}$	T_m	T_{delay}		Stress	Experience/ training	Task complexity	Procedure level	Decision burden
Expansive time (>60)	Favorable	HFE 1	6hr	20min	1min	0min	360min	Moderately high	High	Nominal	High	Low
	Unfavorable	HFE 2	11.5hr	10min	4min	9hr	150min	Moderately high	Low	High	Nominal	High
Nominal time (>30 and <=60)	Favorable	HFE 3	60min	10min	10min	0min	60min	Moderately high	High	Nominal	High	Low
	Unfavorable	HFE 4	60min	20min	20min	0min	60min	Extremely high	Low	High	Low	High
Urgent time (>10 and <=30)	Favorable	HFE 5	20min	18min	1min	0min	20min	Extremely high	High	Nominal	High	Nominal
	Unfavorable	HFE 6	30min	19min	3min	7min	23min	Extremely high	Low	High	Low	High
Extremely urgent time (<=10)	Unfavorable	HFE 7	70min	4min	5min	60min	10min	Extremely high	Low	High	Nominal	High

Fig. 1 shows the results of the comparison of diagnosis HEPs with favorable PSF influences. First, CBDT/HCR represents the highest HEPs. In particular, HEPs of CBDT are adopted as final diagnosis HEPs in expansive time (HFE 1) and nominal time (HFE 3), while HEP of HCR is determined as the final one in urgent time (HFE 5). Second, SPAR-H and K-HRA have relatively low probabilities than the other HRA methods. These are highly affected by positive PSF effects. In addition, HEPs of ASEP have the probabilities between these of SPAR-H (or K-HRA) and CBDT/HCR, and these are estimated by only time curve without adjustment of PSFs.

Fig. 2 represents the results of comparison on diagnosis HEPs with unfavorable PSF influences. First, CBDT/HCR, SPAR-H, and K-HRA have a similar range of HEPs in the group with unfavorable PSF influences. SPAR-H and K-HRA are highly affected by negative PSF influences. CBDT/HCR selects HEP of CBDT on HFE 2 with the reflection of PSFs, and HEPs of HCR on the other HFEs which are followed by time available. Second, ASEP has relatively lower HEPs than any other methods, because it does not consider PSF effects or auxiliary approach such as CBDT.

3.3. Comparison of execution HEPs

Execution HEPs for 7 post-initiators are analyzed on 1) ASEP, 2) THERP, 3) SPAR-H, and 4) K-HRA.

Fig. 3 represents the results of the comparison of execution HEPs with favorable PSF influences. ASEP shows the highest execution HEPs, then K-HRA, THERP, and SPAR-H in order.

Fig. 4 shows the results of the comparison of execution HEPs with unfavorable PSF influences. First, SPAR-H shows the lowest HEPs on all the HFEs. Second, in the case of HFE 2, ASEP has the highest HEP, then K-HRA, THERP and SPAR-H in order, while ASEP, THERP, and K-HRA estimate same HEPs on HFE 4, 6, and 7.

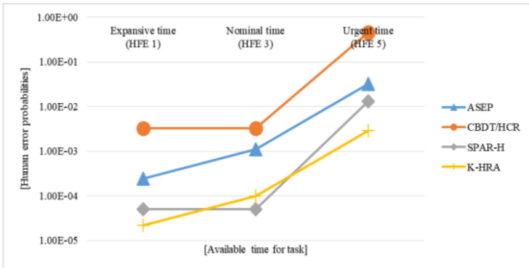

Fig. 1. Diagnosis HEPs with favorable PSF influences

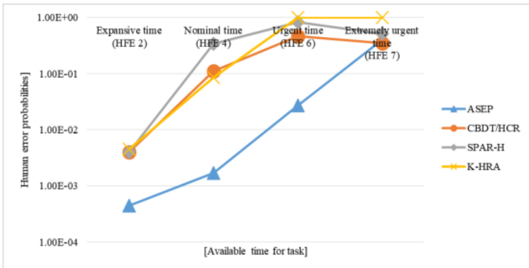

Fig. 2. Diagnosis HEPs with unfavorable PSF influences

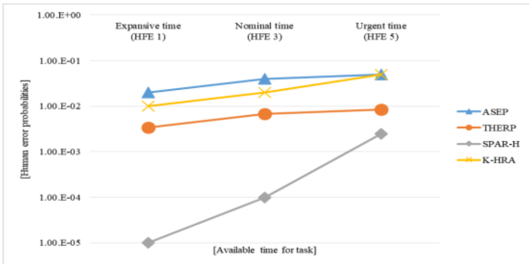

Fig. 3. Execution HEPs with favorable PSF influences

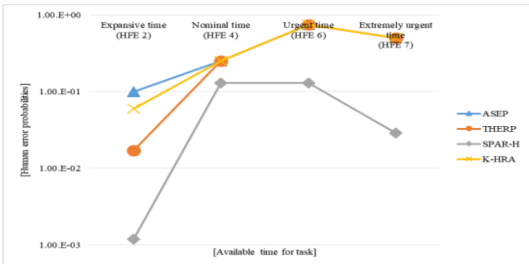

Fig. 4. Execution HEPs with unfavorable PSF influences

3.4. Comparison of final HEPs

Final HEPs for 7 post-initiators are calculated by 1) ASEP, 2) EPRI method (CBDT/HCR+THERP), 3) SPAR-H, and 4) K-KRA.

Fig. 5 represents the results of comparison on final HEPs with favorable PSF influences. As a result, ASEP, CBDT/HCR+THERP, and K-HRA estimate similar ranges of HEPs, while SPAR-H shows relatively lower final HEPs than any other methods.

Fig. 6 shows the results of comparison on final HEPs with unfavorable PSF influences. All the HRA methods estimate similar ranges of HEPs, according to the available time for the task.

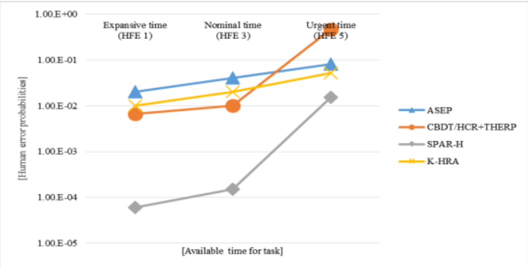

Fig. 5. Final HEPs with favorable PSF influences

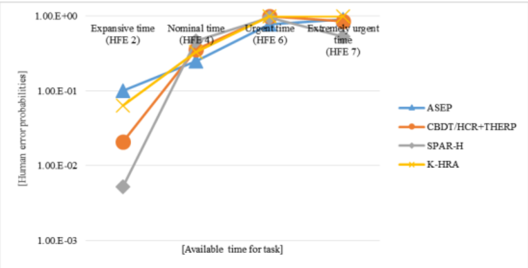

Fig. 6. Final HEPs with unfavorable PSF influences

4. Discussion

This section includes the findings from the comparison of diagnosis, and execution, and final HEPs.

- Finding 1: Diagnosis HEPs of K-HRA and SPAR-H are sensitive to the PSF influences.
- Finding 2: HEPs of CBDT/HCR are partially affected by PSF influences and time available for the task, and have averagely higher diagnosis HEPs in comparison with the other methods.
- Finding 3: ASEP uses only time curve for estimating diagnosis HEPs, which are constant regardless of PSF influences.
- Finding 4: ASEP, THERP, and K-HRA estimates higher probabilities for execution portion than SPAR-H when PSF influences are favorable.
- Finding 5: K-HRA has execution HEPs between those of ASEP and THERP.
- Finding 6: Execution HEPs of ASEP, THERP, and K-HRA are affected by the number of sub-tasks, while action available time has an effect on execution HEPs of SPAR-H.
- Finding 7: The group with unfavorable PSF influences makes a similar range of HEPs on four HRA methods, while HEPs of SPAR-H represents relatively low HEPs in a group with favorable PSFs.

5. Conclusion

The result of this study could be used as reference data to compare the human error probabilities from four HRA methods. It is expected to contribute to overcoming the uncertainties and limitations of HRA by deriving acceptable values for the HRA results.

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