Task Analysis of Emergency Operating Procedures for Generating Quantitative HRA Data

Yochan Kim [a*], Jinkyun Park [a], Seunghwan Kim [a], Sun Yeong Choi [a], Wondea Jung [a], Inseok Jang [a]
[a]*Korea Atomic Energy Research Institute 150, Dukjin, Yuseong, Daejeon, Korea*
[*]*Corresponding author: yochankim@kaeri.re.kr*

1. Introduction

In the probabilistic safety analysis (PSA) field, various human reliability analyses (HRAs) have been performed to produce estimates of human error probabilities (HEPs) for significant tasks in complex socio-technical systems [1]. To this end, Many HRA methods have provided basic or nominal HEPs for typical tasks and the quantitative relations describing how a certain performance context or performance shaping factors (PSFs) affects the HEPs [2].

In the HRA community, however, the necessity of appropriate and sufficient human performance data has been recently indicated [3]. This is because a wide range of quantitative estimates in the previous HRA methods are not supported by solid empirical bases [4]. Hence, there have been attempts to collect HRA supporting data [5,6]. For example, KAERI has started to collect information on both unsafe acts of operators and the relevant PSFs [6]. A characteristic of the database that is being developed at KAERI is that human errors and related PSF surrogates that can be objectively observable are collected from full-scope simulator experiences. In this environment, to produce concretely grounded bases of the HEPs, the traits or attributes of tasks where significant human errors can be observed should be definitely determined. The determined traits should be applicable to compare the HEPs on the traits with the data in previous HRA methods or databases.

In this paper, the analysis results of the emergency task in the procedures (EOPs; emergency operating procedures) that can be observed from the simulator data are introduced. The task type, component type, system type, and additional information related with the performance of the operators were described. In addition, a prospective application of the analyzed information to HEP quantification process was discussed.

2. HEPs in Previous HRA Method and Database

Because the purpose of human performance data development is to support the HEPs in the developed HRA methods or databases, it is essential to review and compare the previous HRA method and databases. The nominal HEP types regarding the main control room operators in THERP [7], ASEP [8], K-HRA [9], SPAR-H [10], HEART [11], HCR [12], Phoenix [13] and CBDT [14] methods, GRS HEP list [15], CORE-DATA [16] can be summarized as follows.

- THERP [7]
  - Procedure omission (procedure; step; instruction)
  - Information gathering omission and commission (oral instruction recall; display selection; indicator reading)
  - Manipulation commission (control selection; use of rotary control or two-position switch; etc.)
- ASEP [8]
  - Diagnosis (time-based)
  - Execution (step-by-step; dynamic)
- K-HRA [9]
  - Diagnosis (time-based)
  - Execution (simple; step-by-step; dynamic)
- SPAR-H [10]
  - Diagnosis
  - Execution
- HEART [11]
  - Task characteristic (task familiarity; procedure; supervision; complex task (high knowledge required); urgency; low attention; training; system aids)
- HCR [12]
  - Skill/Rule/knowledge based behaviors
- Phoenix [13]
  - Information (data not obtained; data collected but dismissed; key alarm not responded; data incorrectly processed; decision to stop gathering data; data incorrectly processed)
  - Decision (skip procedure step; postpone procedure step; deviate from procedure; plant/system state misdiagnosed; decide to wait for more information; decide to delay action; decide to take alternate action
  - Action (unintentional delay; incorrect operation of component or system; select wrong component or system; skip action on one or more components)
- CBDT [14]
  - Availability of information
  - Failure of attention
  - Misread/miscommunicate data or information
  - Information misleading
  - Skip a step in procedure
  - Misinterpret instruction in procedure
  - Misinterpret decision logic in procedure
  - Deliberate violation of procedure
- GRS HEP list [15]
  - Errors of omission (e.g., valve open; signal operation; key control operation; repeated discontinuous control of pump pressure; valve position recognition)
  - Execution errors: cognitive errors in identifying or defining the task (e.g., indicator verification)
  - Execution errors: errors in action execution control (e.g., key, pushbutton, and rotary control operation; manual control of water level

- · Too small sample (signal confirmation, abnormal indicator observation, disturbance indicator response)
- − CORE-DATA [16] (Each HEP is attributed with the error mode, human action type, equipment type, and so on.)
  - · External error mode i (action erroneously completed; action omitted; extraneous action(s) completed)
  - · External error mode ii (e.g., data not available; incorrect quantity - too little; incorrect quantity - too much; incorrect quantity - too much or too little; incorrect repetition; incorrect selection)
  - · Human action 1 (e.g., communication; mediational: information processing; mediational: problem solving and decision making; motor processes: complex continuous; motor processes: simple discrete)
  - · Human action 2 (e.g., aligns; analyzes; calculates; chooses; closes; communicates)
  - · Cognitive error1 (e.g., attention; decision making; long term memory)
  - · Cognitive error2 (e.g., mistake among alternatives; procedural shortcut; risk recognition failure; slip)
  - · Equipment 1 (break; components; control - not identified; control - various; data not available; dials, meters, gauges; display – general)
  - · Equipment 2 (e.g., valve; vessel; operations on site; maintenance on site; administration system; central control room)

From the above HEP types, the HEPs calculated from new human performance data are required to contain the following information.

- − Task type or Error type: This includes both omission and omission types of errors and reflects the cognitive process of human behaviors. The interface characteristics are also included in execution task types.
- − Component types: HEPs related with key controls or components such as a pump or valve can be estimated.
- − System type or target component: An HEP regarding a significant component, indicator or system such as residual heat removal service water system is considered.

3. Task Analysis of EOPs

In this study, the tasks in the Westinghouse-type of EOPs including all optimal recovery procedures and some functional recovery procedures were analyzed. To do so, the task type, component type, system type, target component and related operator were defined considering the abovementioned requirements.

3.1 Task Type

Table I shows the task types and related error types. From the analyzed EOPs, 281 'information gathering and reporting – checking discrete state' type of tasks was found, the 'information gathering and reporting – measuring parameter' type of tasks was observed 280 times, the 'response planning and instruction using procedure' type of tasks were found 1273 times, the frequency of the 'situation interpreting without explicit guide of document' type of tasks was 6, the 'manipulation' task occurred 509 times, and the 'notifying to external agent' type of tasks took place on 42 occasions. Because the 'unauthorized control' behavior means a control in which the procedures are not guided, this type of tasks were not examined during the EOP task analysis.

Table I: Task and Error Type

Task Type	Subtask Type	Error Mode
Information gathering and reporting – checking discrete state	Verifying alarm occurrence	(omission error, commission error)
	Verifying state of indicator	
	Synthetically verifying information	
Information gathering and reporting – measuring parameter	Reading simple value	(omission error, commission error)
	Comparing parameter	
	Comparing in graph constraint	
	Comparing for abnormality	
	Evaluating trend	
Response planning and instruction using procedure	Transferring procedure	(omission error, commission error)
	Transferring step in procedure	
	Executing step in procedure	(omission error)
	Directing information gathering	(omission error, commission error)
	Directing manipulation	
	Directing notification	
Situation interpreting without explicit guide of document	Diagnosing	(omission error, commission error)
	Identifying overall status	
	Predicting	
Manipulation	Manipulating simple (pushbutton) control	(omission error, wrong device, wrong direction)
	Manipulating simple (rotary) control	
	Manipulating dynamically	
Notifying to external agent	-	(omission error, commission error)
Unauthorized control	-	(commission error)

3.2 Component Type

The component type was defined based on the component list in NUREG/CR-6928 [17]. However, some similar components such as a breaker and circuit breaker were merged, and infrequent components in the EOPs were not counted. Table II presents the considered component types in this analysis. The numbers of each component for the manipulation tasks in the EOPs are also given in Table II.

Table II: Component Type

Component	Observed frequency
Air Compressor	5
Breaker	18
Control Rod Drive	2
Controller	1
Damper	1

EDG (emergency diesel generator)	3
Fan	1
Heat exchanger	4
Mode Switch	4
Pump	101
Signal	49
Valve	353

3.3 System Type

The system type was determined by aggregating the system described in the EOPs and P&IDs (piping and instrumentation diagrams) of the Westinghouse-type and OPR (optimized power reactor)-type plants. The target systems for each manipulation task were identified using the determined system types.

Table III: System Type

System		Observed frequency
AFWS	Auxiliary Feedwater System	47
CCWS	Component Cooling Water System	15
CIS	Containment Isolation System	2
CS	Condensate System	2
CSS	Containment Spray System	17
CVCS	Chemical Volume and Control System	98
EDG	Emergency Diesel Generator System	3
EPS	13.8kW Power System	18
ESFAS	ESF Actuation System	49
ESWS	Essential Service Water System	1
HVAC	Containment Building HVAC	2
IAS	Instrument Air	6
LSAS	Non-radioactive Liquid Sampling & Analysis System	8
MFWS	Main Feedwater System	16
MSS	Main Steam System	85
NDS	Nuetron Detection System	2
PCWS	Plant Chilled Water System	1
PZR	Pressurizer	44
RCS	Reactor Coolant System	74
RHR	Reactor Protection System	2
RPS	Shutdown Cooling System	2
SDCS	Steam Generator Blowdown System	14
SGBD	Safety Injection System	15
SIS	Main Turbine & Auxiliary	11
TBN	Auxiliary Feedwater System	3

3.4 Target Component and Related Operator

To enable detailed error analysis of a certain component operation, target components for manipulation tasks were described. In addition, for each task type, the operator who mainly performs the task is also commented.

The example of the analyzed data can be seen as Figure 1.

4. Application to Quantitative Data Generation

4.1 Calculating HEPs

Several types of HEPs can be estimated using the analyzed information. The base equation of the HEP calculation is as follows [6].

$$\text{HEP}_i = \frac{n_i}{m_i} = \frac{n_i}{n_i + 0_i}.$$

Here, n_i is the frequency of errors observed in a certain type *i*, m_i is the number of total possible situations of type *i*, and 0_i is the frequency of situations of type *i* where no error is observed.

To estimate m_i, the path of the procedure that an operator should follow in a given simulation situation is examined by the analyzer. In addition, the analyzer also identified unsafe actions using the UA identification process explained in [18]. If the optimal path of the procedure is determined, because the task's attributes are described in each instruction of the EOPs (Figure 1), the HEP of a certain type can be easily calculated.

4.2 Estimating effects of PSFs on HEPs

To statistically estimate the quantitative relation between the PSFs and HEPs, it is necessary to systematically develop the data including erroneous and non- erroneous behaviors with PSF variables [4]. The task analysis results of this study allow collecting both information of unsafe actions and safe actions, because the performance of the task where no error is observed in the optimal path of a procedure can be seen as a safe action. Furthermore, the characteristics of the performed

세부단계	조치사항	대상기기수	TaskType	subTaskType	담당운전원	기기ID	기기유형	관련시스템
0-	원자로트립을 확인한다	1	RI	Entering	SS			
0-cb-1	모든 제어복 바닥등 : 켜짐	1;1	RI;CS	Information;Indicator	RO			
0-cb-2	RX TRIP BKR 및 우회 BKR : 개방됨	1;1	RI;CS	Information;Indicator	RO			
0-cb-3	PR 중성자 속 : 감소중	1;1	RI;MP	Information;Trend	RO			
0-cb-4	IR 중성자속 : 감소중	1;1	RI;MP	Information;Trend	RO			
R0-①	수동으로 원자로를 트립시킨다	-	-	-				
R0-①-cb-1	SF-HS-319	1;1	RI;MA	Manipulation;Pushbutton	RO	SF-HS-319	Control Rod Drive	RPS
R0-①-cb-2	SF-HS-309	1;1	RI;MA	Manipulation;Pushbutton	RO	SF-HS-309	Control Rod Drive	RPS
R0-②	만일 원자로가 트립되지 않으면 회복-3.1 (원자로 정지불능시 조치) 단계 1.0으로 간다	1	RI	Procedure	SS			

Figure 1. snapshot of task analysis results based on Westinghouse-EOPs

tasks such as surrogates regarding the task complexity and procedure quality can be analyzed from the instruction sentences in EOPs [18]. We expect that it is possible to generate data for statistically analyzing the PSF-HEP relations from the information obtained in this study.

5. Summary and Future Works

In this study, task characteristics in a Westinghouse-type of EOPs were analyzed with the defining task, component, and system taxonomies. The taxonomies will be extended to entail the characteristics in other types of plants such as an OPR or other situations such as abnormal situations.

Acknowledgment

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea Grant, funded by the Korean government, Ministry of Science, ICT & Future Planning (Grantnumber2012M2A8A4025991).

REFERENCES

[1] B. Hallbert, D. Gertman, E. Lois, J. Marble, H. Blackman, & J. Byers, The use of empirical data sources in HRA, Reliability Engineering & System Safety, 83(2), 139-143, 2004.

[2] K. M. Groth and L. P. Swiler, Use of a SPAR-H bayesian network for predicting human error probabilities with missing observations, Proceedings of the International Conference on Probabilistic Safety Assessment and Management (PSAM 11), Helsinki, Finland, 25–29 June, 2012.

[3] Y. J. Chang, et al., The SACADA database for human reliability and human performance, Reliability Engineering & System Safety, 125, 117-133, 2014.

[4] Y. Kim, J. Park, W. Jung, I. Jang, & P. H. Seong, A statistical approach to estimating effects of performance shaping factors on human error probabilities of soft controls, Reliability Engineering & System Safety, 142, 378-387, 2015.

[5] Y. Kim, J. Park, W. Jung, A Survey of data-based human reliability analysis approaches, The 1st Asian Conference on Ergonomics and Design (ACED 2014), 2014, Jeju, Korea.

[6] Y. Kim, J. Park, W. Jung, HRA Data Collection from the Simulations of Abnormal Situations, Transactions of the Korean Nuclear Society Autumn Meeting, Pyeongchang, Korea, October 30-31, 2014.

[7] A. D. Swain, H. E. Guttmann, Handbook of human reliability analysis with emphasis on nuclear power plant applications, NUREG/CR-1278. Washington, DC: Sandia National Laboratories, 1983.

[8] A. Swain, Accident Sequence Evaluation Program Human Reliability Analysis (ASEP HRA) Procedure, NUREG/CR-4772, US NRC, 1987.

[9] W. D. Jung, D. I. Kang, J. W. Kim, Development of a standard method for HRA of nuclear power plants - Level I PSA full power internal HRA, KAERI/TR-2961/2005, 2005.

[10] D. Gertman, H. Blackman, J. Marble, Byers, C. Smith, The SPAR-H human reliability analysis method, NUREG/CR-6883. Idaho National Laboratory, prepared for U. S. NRC, 2004.

[11] J. C. Williams, HEART - A Proposed Method for Assessing and Reducing Human Error, Proceedings of the 9th Advances in Reliability Technology Symposium, University of Bradford, 1986.

[12] G. Hannaman, A. Spurgin, Y. Lukic, Human Cognitive Reliability (HCR) Model for PRA Analysis, Draft Report, NUS-4531, EPRI Project, 2170-3, 1984.

[13] A. Mosleh, S. H. Shen, D. L. Kelly, J. H. Oxstrand, K. Groth, A Model-Based Human Reliability Analysis Methodology, In Proceedings of the International Conference on Probabilistic Safety Assessment and Management (PSAM 11), Helsinki, Finland, 2012.

[14] G.W. Parry, A.N. Beare, A.J. Spurgin, P. Moieni, An approach to the analysis of operator actions in probabilistic risk assessment, EPRI TR-100259, 1992.

[15] W. Preischl, and M. Hellmich, , Human error probabilities from operational experience of German nuclear power plants, Reliability Engineering and Systems Safety, 109, 150-159, 2013.

[16] B. Kirwan, G. Basra, S. E. Taylor-Adams, CORE-DATA: a computerised human error database for human reliability support, Proceedings of the 1997 IEEE Sixth Conference on Global Perspectives of Human Factors in Power Generation, (pp.9/7-9/12), Florida, Jun 1997.

[17] A.L. Eide Steven, et al., Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, NUREG/CR-6928, US Nuclear Regulatory Commission, 2007.

[18] J. Park, W. Jung, S. Kim, S. Y. Choi, Y. Kim, The definition of an unsafe act and the associated analysis guideline with respect to training records collected from simulated off-normal conditions, KAERI/TR-5966/2015, KAERI, 2015.