Findings from APR1400 Human Reliability Data Analysis: Human Performance in Digitalized Control Room

Yochan Kim[a*], Jinkyun Park [a], Mary Presley [b]
[a]*Korea Atomic Energy Research Institute 111, Daedeok-daero 989, Yuseong-Gu, Daejeon, Korea*
[b]*Risk & Safety Management, Electric Power Research Institute, 1300 West WT Harris Boulevard, Charlotte, NC 28262*
[*]*Corresponding author: yochankim@kaeri.re.kr*

1. Introduction

The empirical data collected via observations of the licensed operator behaviors in full-scope simulators provide useful information to derive insights related to human reliability assessment. In particular, the data from high fidelity of simulator is very important to predict the operator reliability in a newly introduced digital interface environment. This paper summarizes the reliability and performance characteristics of APR1400 operators obtained from the analysis process of the empirical data. This data was generated from the APR1400 training simulators with licensed operators based on the HuREX (Human reliability data extraction) system developed by KAERI [1][2]. These findings are considered to be a technical basis for predicting the operator characteristics of the digitalized main control room (MCR).

2. HuREX Data Collection from APR1400 Simulator

The HuREX data is generated by identifying the human errors and successful behaviors from the raw data. The raw data includes (1) video records containing operator discourses and screen operations, (2) navigation logs of the digital information systems, (3) records of key plant parameters, (4) operation logs of computer-based procedures, (5) malfunction information inputted in the simulation, and (6) questionnaire information obtained after each simulation.

The data analyzer distinguishes a human error by defining it as "an action inappropriately taken by plant personnel, or not taken when needed, resulting in a degraded plant safety condition." [3]. Therefore, if the behavior that is deviated from the standards such as the procedures has any causality with one of the following situations, it is determined as a human error.

- Inappropriate component operations
- Inappropriate changes of procedural steps
- Inappropriate communications with an MCR outside

In this system, the data unit of the operator performance is a primitive task defined by procedure instructions and the command-and-control protocol. As can be seen in Fig. 1, there are different task levels in nuclear system operations [4]. The HuREX system defines the primitive task at the action level. The action level of tasks are defined based on the procedure instructions; hence, they are not changed according to types of human-machine interfaces.

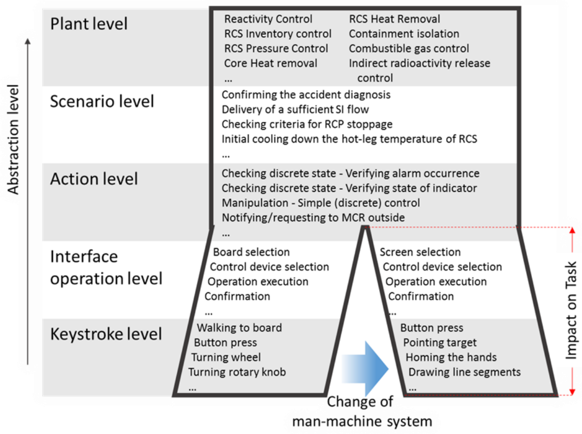

Fig. 1. Task definition spectrum [4]

The context information of each task performance is also gathered in the database. Information for about 50 variables representing several performance shaping factors such as operator experience, procedure quality or clarity, task complexity, stress, and operator's attention on task was produced in this collection.

3. Findings from Data Collection and Analysis

3.1 Performance Time

As shown in [5], the human performance time regarding the procedure following behaviors was well described by the log-normal distribution, which is expressed by $\ln(X) \sim N(\mu, \sigma)$. In this work, the two parameters were estimated from the periods from the reactor trip to the completion of the diagnostic action procedure by the maximum likelihood estimation (μ = 2.044, σ = 0.330).

The average time from the trip to the diagnosis in the digitalized MCR was 8.166 min. Compared with the average diagnosis period estimated from OPERA (operator performance and reliability analysis) database [6] (5.807 min), the average time of digitalized MCR was larger than the average time of analog-style MCR. This difference is attributable to the fact that the computer-based procedure requires operators to click all procedural instructions that have been carried out. This function is beneficial to prevent operators from arbitrarily skipping procedures, but it also requires time for operators to control the procedure software.

In terms of variability of performance time, the coefficient of variation (i.e., the standard deviation divided by the mean) of the diagnosis time was calculated to be 0.354 (2.888 min / 8.166 min). Compared with the coefficient of variation for the diagnosis time estimated from the OPERA database [6] (0.530), the variability of diagnosis time in digitalized MCR is smaller than one in analog-style MCR. The reason why the variability of the performance time in the digital control room has decreased is related to the characteristics of the computerized procedure. Because the operators had to click all placekeepings of the computer-based procedure one by one, the difference in performance time between operators was reduced.

3.2 Detection and Monitoring Errors

No omission error was found in the detection and monitoring tasks. 27 commission errors in those tasks were identified from the 22792 task performances [2]. Many errors were related to the initial emergency situations because the operators had to perform a variety of tasks and also understand overall accident situation at the same time. Although, it is viewed that the reliability regarding the plant information acquisition has improved compared to the reliability in the analog systems.

3.3 Cognitive Errors in Procedure Followings

During the procedure following activities, various kinds of tasks can be carried out: (1) entering a step in a procedure, (2) transferring procedures, (3) transferring steps in a procedure, (4) directing information gathering, (5) directing manipulation, and (6) directing notification/request. From the analysis of the HuREX data [2], it was revealed that the human error probabilities depend on the types of tasks. For example, the task transferring a step had a base error probability of 2.16E-02 while the error probability of entering a step in a procedure was 7.78E-04.

In addition, it was found that the clarity of labels, instructions, or structures between instructions can have a significant impact on the reliability of cognitive activities. The procedure quality has been recognized as an important factor of any safety-critical system. However, in the environments employing the computer-based procedures, the operators tended to rely more on the phrases dictated by procedures. For this reason, it is believed that the importance of the quality of the procedure was more emphasized in the APR1400.

3.4 Execution Errors

Like the probabilities of the cognitive errors in procedure following behaviors, and like the execution error probabilities in the analog-style MCR [1], the human error probability of the execution errors in the digitalized MCR can vary depending on the task types. For example, the base human error probability for simple discrete manipulation was estimated to be 5.35E-03, while the error probability for dynamic manipulation was expected to be 3.44E-02.

The most interesting observation regarding execution reliability was the occurrence of human errors that are attributed to secondary tasks or screen navigation. Some previous papers such as [7], [8], and [9] emphasized that human errors can occur during the screen navigation actions for searching the components to be manipulated or detecting plant information. However, the execution error related to the screen navigation was not observed in this data collection. The first reason for this result is related with the meanings of the task and the human error defined in HuREX. The HuREX system identifies a human error when the behavior negatively affects the plant situation. In some cases, the operators might wrongly switch the screen but they could recover it soon to find the appropriate screen. This kind of errors were not captured by the HuREX definition, because the wrong screen change does not affect the plant conditions or the procedure flows. The second reason is the level of skillfulness. Many previous experiments regarding the soft controls were conducted with student operators. However, the operators who has been trained in the simulators became very familiar with the system; hence, it was easy to find the screen. Lastly, the interface configuration also contributed to the absence of the navigation errors. The digital information system of the APR1400 is designed to be able to reach any screens from the main screen by one or two conversions of screens. It is judged that the shallow structure of plant displays assisted the operators so as not to significantly impair the usability of the information system.

3.5 Recoverability

Similar to the analysis results of the HuREX data collected in the previous MCR [10], a small amount of data on recovery success in the simulator data were collected than expected. This is because the recording period of raw data was mostly within 3-40 minutes, so there was not enough time to observe recoveries. There is another reason that it was difficult to recover the human errors because most errors occurred during the initial periods of emergency situation and the operators continuously received different tasks to be performed.

The recovery activities based on instrumentation or operator knowledge are mainly observed during the data collection. However, it should be noted that there are various sources of the recovery behaviors, for example:

- Recovery by a shift change
- Recovery by an apparent cue
- Procedure recheck in a stable status
- Monitoring of safety-critical functions by the shift technical advisor
- Recovery by a procedure step confirming the action

Each kind of recovery behavior has a dependency on their relevant errors of operators. The recovery probabilities could thus be estimated with considerations of the dependency between human errors and recovery actions.

4. Conclusions

It is expected that the digital interface systems can provide a new opportunity to improve operator reliability and performance. Although many ergonomic issues remain, the joint performance of the man-machine system will be enhanced if the system is optimized through continuous human behavior observations and analyses. Since the operation experience of the APR1400 is still relatively small, additional collection and analysis of human reliability data is desirable after accumulation of the operation experience.

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