Simulator-based Time Reliability Curve for HRA of Digitalized Main Control Room

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1. Introduction

Human reliability analysis (HRA) of Shinkori unit 3, the first APR1400 nuclear power plant (NPP) with fully digitalized main control room (MCR), was performed using the THERP method [1]. The THERP estimates human error probability (HEP) of the diagnosis part of a human failure event (HFE) using a time reliability curve (TRC). However, there has been a question whether the THERP TRC can be used for the HRA of APR1400 NPPs since the TRC was proposed almost 40 years ago in the U.S. for the HRA of analog type man-machine interface system (MMIS). To answer this question, it is necessary to develop a new TRC reflecting the design and operational characteristics of digitalized MMIS. This paper introduces a method of simulator data collection and analysis to generate a diagnosis TRC for the HRA of digitalized advanced MCR [2].

2. Methods and Results

2.1 THERP TRC

The risks of NPPs are clearly correlated to the response reliability of the crew who operates the plant during abnormal events or accidents. There were a few studies before the 1970s that scrutinized the correlation of response times and human reliability that would be used to develop similar time-dependent models for hardware. The concept behind the TRC approach is that a crew will eventually response to an accident given enough time, so the estimated HEP decrease depending on the time available before an accident reaches an irreversible point.

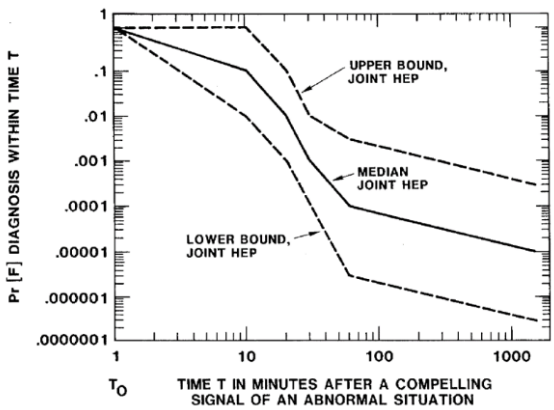

Fig. 1. THERP TRC [1]

One of the representative studies was the TRC of THERP developed by Swain [1]. As shown in Fig.1, THERP proposed three TRCs to predict the diagnosis HEP median value and distribution (5% and 95%) as a function of time. The diagnosis HEP decreases as the time from the event occurring increases and is assumed to be lognormal over time. Swain also suggested the use of performance shaping factors (PSFs) to modify the TRC. The THERP TRC was derived from expert judgment considerations that were guided by some simulator data undertaken by General Physics and Oak Ridge.

2.2 Method to Generate a TRC using Simulator Data

To support HRA, we have analyzed simulator records to generate plant specific HRA data such as HEP, performance time (PT), and correlations between PSFs and HEPs using HuREX (Human Reliability data Extraction) [3]. As mentioned in the previous section, using the THERP TRC for the HRA of Shinkori unit 3 PSA has become a technical issue whose validity should be proven. Among the various HRA data generated by HuREX, part of the PT data can be used to produce a kind of plant specific TRC.

The data obtained from simulator records include time required to detect and diagnose a given event and formulate an appropriate response to the event. Then the time data are sorted with ascending order of time. Afterwards, the TRC can be derived by the following equation:

$$Pr(TRCi) = Pr(\text{response time} > ti) = 1 - i/(n+1),\ i = 1, 2, 3, \ldots, n. \quad (1)$$

where, i is the i'th data point, ti is the i'th time in the ascending order of response time, and n is the total number of samples.

To generate a TRC, we first need to collect time data taken to diagnose a simulated event. Time data means the time purely taken by a crew to diagnose (signal perception, situation diagnosis, and response planning) a simulated event, referred as "DiagTime" in Fig. 2. To extract the time data from simulator experiments, we need to design simulation scenarios, including a few abnormal and/or emergency events, and collect the relevant time data for given events.

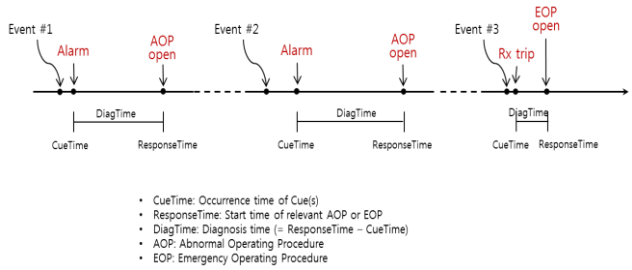

Fig. 2. Data points for extracting diagnosis times in a simulated scenario.

2.3 Results of an Application

For a case study, we applied the proposed method to generate a TRC for a reference NPP. The simulator data used in the case study were collected from the full-scope training simulator of the reference NPP with fully digitalized advanced MCR. We collected simulator records from the regular training programs required for the MCR operators working at the reference plant. A total of 12 crews participated in the data collection, and simulator logs and records were secured with regard to eight simulated scenarios, including 18 abnormal and emergency events.

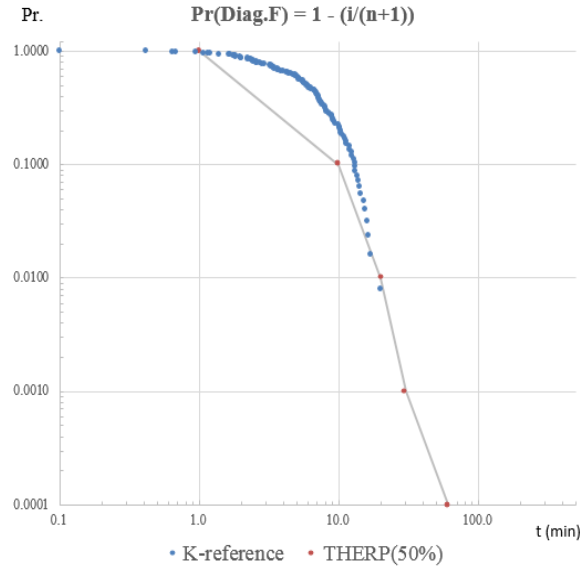

Fig. 3. TRC generated from the application study.

A TRC, as shown in Fig. 3, was generated using total 125 data points. We also generated two additional TRCs, each for abnormal events (69 data points) and diagnosis events (56 data points), respectively. The TRC of abnormal events shows a similar pattern with the TRC of Fig. 3, but the TRC of emergency events is different from the TRC shown in Fig. 3 or the TRC of abnormal events. The data shows that there is not much difference in response times for emergency events. We interpret it is because the way of emergency responses using EOPs after reactor trips is more formal than that in abnormal situations. According to basic statistics, the average diagnosis time for the emergency events was 9.1 minutes, which was larger than the average time for the abnormal cases, 4.6 minutes. However, the standard deviations were almost the same in both the emergency and the abnormal events, which were 2.9 and 2.8 minutes respectively.

We compared the TRC obtained from the study with the THERP TRC. It shows that the probability of diagnosis failure estimated by the TRC of the reference plant is higher than the median of THERP TRC in the time interval from 1 to 10 minutes. However, even within 10 minutes, the TRC is smaller than the upper bound of the THERP TRC. After 10 minutes, it is almost similar to the THERP median.

3. Conclusions

THERP TRC was used for the HRA of the first APR1400 NPP with digitalized MCR. However, the TRC was developed almost 40 years ago in the U.S. for HRA of analog type MMIS. Therefore, it is necessary to verify the suitability of THERP TRC by using plant specific operating experience or simulator data. To this end, we developed a method for collecting and analyzing simulator data to generate a TRC, which includes guidance on the definition of TRC and timing points to be collected, and the processing of collected data. An application study was carried out using a set of simulator records obtained from the reference plant with digitalized MMIS. The study shows that the proposed method is suitable to generate a TRC for the reference plant.

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