Procedural Behavior Analyzer of MCR Operators in Nuclear Power Plants

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

1. Introduction

When an accident occurs in a nuclear power plant, the operators of the main control room (MCR) diagnose the cause of the accident and execute recovery actions according to accident procedures. However, there are times when operators do not follow all steps of the written procedures for several reasons. Although deviating from the written procedures does not always result in human error, it is also true that these behaviors can become the source of latent errors when coping with the accidents.

Despite many researches regarding human error, a systematic analysis for identifying what kinds of unsafe behavioral patterns and why such patterns occur seems to be very limited. Although traditional approaches provide a retrospective analysis of event sequences, they do not provide statistical and integrated analyses for discovering deviations in multiple behaviors [1-3].

An analysis of multiple behavior sequences of operators has two issues. First, a sufficient number of databases on operator procedure progressions should be obtained. Fortunately, some simulators for MCR operators were recently developed and abundant data has been collected through simulator experiments [4]. Secondly, however, it is also necessary to compare the procedure progressions among many different experiments. Due to abundant human performance data, an appropriate analysis tool should be developed to identify how the steps are linked with others in a human performance database.

In this light, an Operator Procedural Behavior Analyzer, which compares and analyzes the behavioral sequences of operators in conducting emergency operating procedures, was developed based on OPERA DB (Operator Performance and Reliability Analysis DataBase) [4]. The developed tool extracts linear sequences from the OPERA DB and generates a directed acyclic graph. Using this graph, the developed tool presents some patterns or characteristics regarding human performance. Basically, the tool shows a task's complexity based on how diversely operators conduct the task. In addition, the tool provides the location where the operators executed different steps and evidence of why they did so. This paper explains the mechanism of the developed tools and the results generated by the tool.

2. Operator Procedural Behavior Analyzer

2.1 Data

Before explaining the proposed tool, the data we employed are as follows. From the OPERA DB, we employed an event description such as the total execution or diagnosis time, experience of the operators, document usage, and crew performance levels. Fig. 1 shows the schema of the data. The step description of each event was also collected with the ingress time of each step.

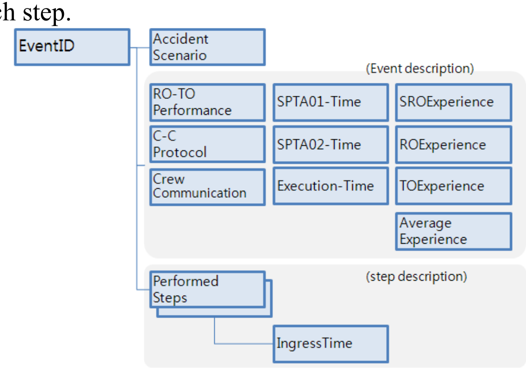

Fig. 1. A graphic representation of data schema used for Operator Procedural Behavior Analyzer.

2.2 Proposed Analyzer

Operator Procedural Behavior Analyzer finds out the procedure progressions of each event for a selected scenario. By sorting the progressions based on the ingress time, the analyzer obtains plain sequences. Then, the analyzer generates a directed acyclic graph using the Partial Order Alignment (POA) algorithm [5]. The POA algorithm is a heuristic to handle a large number of sequences within a short time. It was proved that the algorithm has good performance in bioinformatics and other domains. The below figure depicts an example of a directed acyclic graph, which is generated by the POA.

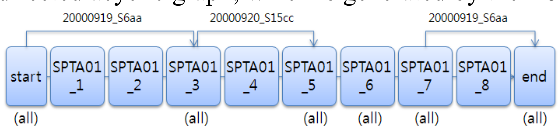

Fig. 2. An example of a directed acyclic graph, which is generated by the POA.

From a directed acyclic graph generated by the POA algorithm, complexity based on sequential variations is estimated for the given scenario. The system calculates the number of branches and nodes of the graph and how many sequences follow a best-practice sequence. Because a simpler graph implies lower sequential complexity, the graph of a lower number of nodes and branches and more following sequences is acceptable. The probability that an operator can follow the best-practice sequence is also calculated. If the graph is simple and many operators follow the same sequence, the probability will be high. A graph complexity based on entropy of information is also calculated [6].

The system can show which sequences diverge from each branch of a generated graph, as well as the characteristic of each sequence by comparing the event descriptions. The system provides the average values of all information and their bar graphs.

A snapshot of the developed analyzer is depicted as in Fig. 3. The analyzer can be divided into four layers. The first layer, which is located at the top of the interface, shows the results of the calculated data. The second layer shows the directed acyclic graphs generated by the POA algorithm. If an analyst clicks on a node of the graph, the analyzer shows the selected node and the subsequent nodes in the third layer, which is under the second layer. Sequences that include the subsequent nodes are also displayed with the average values of their event description. The lowest layer provides bar graphs for the average values of the event description.

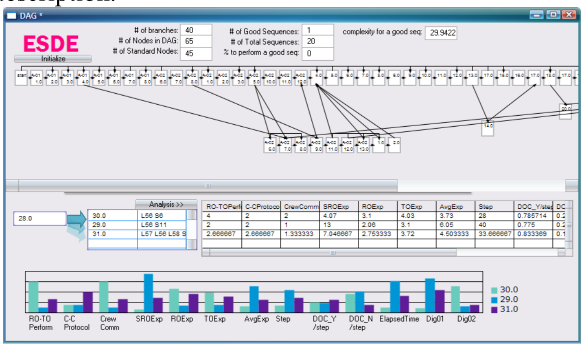

Fig. 3. Operator Procedural Behavior Analyzer.

3. Results

The Opera DB was analyzed using the developed tool. The analyzer generated graphs and showed different complexity estimation values for each scenario. Graphs of the LOCA and SGTR scenarios were not complete because their sequences were too long to be computed by the POA algorithm. However, graphs of the other scenarios were completely formed.

The probabilities that a sequence follows the best-practice sequence were calculated, but all resultant values were close to zero. This is because many branches exist in a graph. Hence, graph complexity based on entropy of information was considered for comparing the scenarios. A scenario list can be sorted based on graph complexity in ascending order: GT, LOOP, LOAF, SBO, SGTR, ESDE, and LOCA. The complexity value was correlated using the average total execution time (Refer to Fig. 4.).

While inspecting the branches, no consistent factors of behavior divergence were found from the results of the compared event descriptions. The bar graph of the analyzer showed various distributions of event descriptions for each branch.

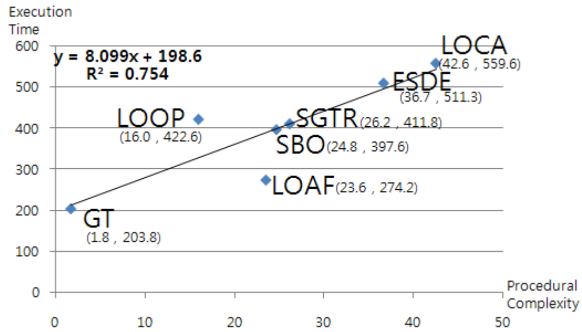

Fig. 4. Procedural complexity estimated by graph complexity is correlated with the total execution time.

4. Discussion and Conclusions

In this paper, we introduced an analyzer to identify unsafe patterns within behavior sequences while executing post-accident procedures. The analyzer depicted how differently operators behaved using directed acyclic graphs and provided quantitative estimators for the complexity of the given scenarios. The complexity estimation was quite significant and correlated with the total execution time. The estimators seem to be related with the operator's unsafe patterns, structures, and lengths of the written procedures and operating contexts.

While inspecting the branches of the generated graphs, event descriptions did not provide sufficient explanations regarding the attribution of a behavior divergence. It is necessary to collect more information such as step descriptions.

The analyzer provided analysts graphical and numeric insight regarding an operator's procedural behaviors. Using the analyzer, we plan to add a technique for determining behavior patterns that can raise the critical degradation of plants. We are also considering developing a technique that simulates how an operator behaves under given conditions. The fully extended analyzer will contribute toward detecting and reducing an operator's unsafe patterns.

REFERENCES

[1] INPO. Human performance enhancement system. INPO 90-005. Atlanta: Institute of Nuclear Power Operations, 1990.

[2] NRC. Development of the NRC's human performance investigation process (HPIP). NUREG/ CR-5455, SI-92-01, vol. 1. Washington, DC: US NRC, 1993.

[3] KEPCO Research Center. Development of Korean HPES for nuclear power plants (II). Final report, 1998.

[4] J. Park, and W. Jung, "OPERA-a human performance database under simulated emergencies of nuclear power plants", Reliability Engineering & System Safety, Vol. 92, no. 4 , p. 503-519, 2007.

[5] C. Lee, C. Grasso, and M. Sharlow, "Multiple sequence alignment using partial order graphs," Bioinformatics, vol. 18, no. 3, p. 452-464, 2002.

[6] D. Bonchev and G. A. Buck, "Quantitative Measures of Network Complexity", In Complexity in Chemistry, Biology, and Ecology, (Eds) D. Bonchev, D.H. Rouvray., Springer, p. 191-235, 2005.