Quantifying the Step Following Level of an Operator in Proceduralized Scenarios

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1. Introduction

In nuclear power plants, operators of the main control rooms cope with abnormal or emergency situations using relevant procedures. However, there exist several features that challenge step-by-step following of the procedures: ambiguous descriptions of procedures, dynamic situations of power plants, operational tendencies of operators, and so on [1, 2]. To identify and manage the features, it is useful to quantifying how compliantly an operator follows the steps of the procedures.

There was little research that measures the step following level of an operator. Kim et al. presented a measure, VPP (variability of procedure progression), to estimate a variability of ways to follow a given procedure [2]. However, VPP has some characteristics to be evaluated. First, VPP score is related with the number of step in each procedure progression. Second, VPP score is also affected by the number of progressions. In addition, VPP score implies a variability of procedure progressions, not a compliance of a progression with the given procedure. If all operators do not follow a sequence of steps in a procedure but show similar procedure progressions, the VPP score of the progressions will be low. Therefore, it is necessary to develop another measure that is capable to explain more closely the step following level.

In this light, we propose a new measure, PCL (procedure compliance level) to estimate how a procedure progression is similar to the standard progressions. This paper introduces the algorithm of this measure and shows its applicability by presenting a result that is applied to a digitalized control room.

2. Algorithm of PCL measure

To evaluate PCL measure, a procedure progression of an operator and a standard procedure progression that should be progressed in typical situations are received as inputs. The standard procedure progression is obtained by relevant procedure and the record of status in the situation. In this case, the PCL score calculated by the below equation:

$$PCL = \frac{Similarity(S_{operator}, S_{standard})}{Similarity(S_{standard}, S_{standard})}, \quad (1)$$

where S is a procedure progression of an operator or standard procedure progression.

The similarity of two progressions is calculated by Smith-Waterman algorithm [3]. The Smith-waterman algorithm is as follows:

$$H(i,0) = 0, \quad 0 \le i \le m$$
$$H(0,j) = 0, \quad 0 \le j \le n$$
$$if\ a_i = b_j, w(a_i, b_j) = w(match)\ or$$
$$if\ a_i \ne b_j, w(a_i, b_j) = w(mismatch)$$
$$H(i,j) = \max \begin{Bmatrix} 0 \\ H(i-1, j-1) + w(a_i, b_j)\ Match/Mismatch \\ H(i-1, j) + w(a_i, "\_")\ Deletion \\ H(i, j-1) + w("\_", b_j)\ Insertion \end{Bmatrix}, \quad 1 \le i \le m, 1 \le j \le n \quad (2)$$

Here, a, b = any steps in two arbitrary procedure progressions, m = length(a), n = length(b), $H(i,j)$ is the maximum similarity-score between a suffix of $a[1...i]$ and a suffix of $b[1..j]$, $w(c, d)$, $c,d \in$ a set of steps $\cup$ {"_"}, and "_" is the gap-scoring scheme.

We assume that every matching state (=$w(match)$) has a score value of 2, mismatching state (=$w(mismatch)$) has a score value of -1, and that other states have a score value of 0.

Fig. 1 shows an example of how the PCL score for two progressions is obtained. If an operator followed a SPTA(standard post-trip action) procedure with a sequence of [ingress,1,2,4,5,6,8,end] when the typical progression is [ingress,1,2,3,4,5,6,7,8,end], the similarity between $S_{operator}$ and $S_{standard}$ is 16. The similarity between $S_{standard}$ and $S_{standard}$ is 20, because there are ten identical steps. Therefore, PCL score of these progressions is 0.8 (=16/20).

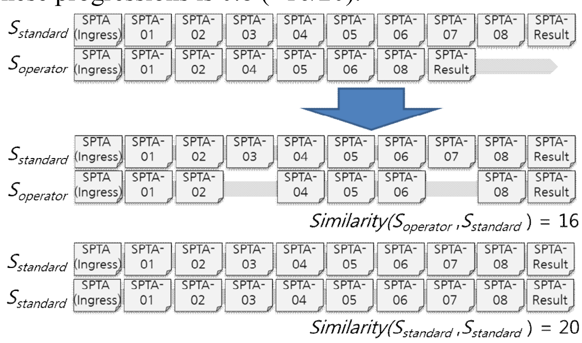

Fig. 1. A process to calculate a PCL score for an progression.

If it is required to calculate PCL score for a lot of progressions, it is difficult to extract exact $S_{standard}$ for each $S_{operator}$. In this situation, $S_{standard}$ is found by the below equation with an assumption that all operators tried to follow the standard procedure progression.

$$S_{standard} = \arg\max_{S_{s.c.}}(Similarity(S_{operator}, S_{s.c.})), \quad (3)$$

where $S_{s.c.}$ is a set of all progressions that are expected as typical progressions.

3. Experiment

3.1 Method

To find relations between PCL measure and workload measures, we conducted three experiments of SGTR (steam generator tube rupture) diagnosis scenario in a full-scope simulator for a control room in APR1400. In this simulator, an SS(senior supervisor) follows computerized emergency operation procedures(EOPs), which prevent the SS arbitrarily skipping steps of EOPs. Hence, the SS usually shows step-by-step following behaviors unless the SS misinterprets the EOP or the EOP does not fully reflect plant's conditions in the SGTR scenario. The EOP provide a flow chart for SSs to diagnose the occurring situations. If the SS has a problem to diagnose SGTR, the SS might shows different progress progression and also high workload for this situation.

The Modified Cooper-harper(MCH) technique is employed to measure the level of a workload, since this is known as one of the most suitable techniques for evaluating an subjective workload [4, 5]. The four operators who participated in each experiment evaluated their workload for a given situation.

3.2 Results

We obtained three procedure progressions for diagnosis of SGTR:
- Experiment-A: [1, 2, 3, 4, 5, 7, 9, 11, 12, 20, 22, 23]
- Experiment-B: [1, 2, 3, 4, 5, 7, 9, 11, 12, 20, 22, 23]
- Experiment-C: [1, 2, 3, 4, 5, 7, 9, 10, 24, 26, 27]

The number in the above list indicates the step indices that the SSs progressed. In addition, we obtained a typical procedure progression for diagnosis of SGTR: [1, 2, 3, 4, 5, 7, 9, 11, 12, 20, 22, 23]. The SSs in the experiment A and B were followed as the typical procedure progression.

Fig. 2 shows the average MCH workload score and the PCL score. It is shown that PCL score is low when average MCH score is high. During experiment B, the SS couldn't exactly follow the diagnosis procedure, because the plant condition that was changing due to SGTR was not perfectly matched with the descriptions of the procedure.

3. Discussion and Conclusion

The result of this study does not imply that PCL score is always negatively related with subjective workload. However, it can be predicted that a feature that complicates the diagnosis task affects the operator's procedure progressions as well as their subjective workload. In reference to this issue, Braarud and Kirwan showed that task complexity can be caused by ambiguous or misleading information and the high complexity affects the subjective workload [6, 7]. This study supports these reports through quantitative measures.

This study shows a possibility of the PCL measure to predict or explain performance of operators who manage proceduralized tasks. Through more investigations with large samples, we believe that we can approach clearer understanding of human reliability in nuclear power plants.

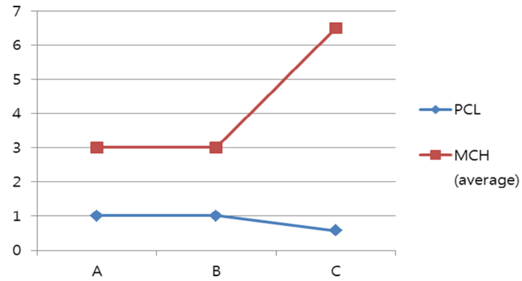

Fig. 2. The PCL and MCH scores of three experiments.

Acknowledgement

This research was supported by a Nuclear Research & Development Program of the National Research Foundation (NRF) grant funded by the Korean government. (Grant code: 2012-011506).

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