Suggestion of the Eye-tracking system based Fitness-for-duty Evaluation Methodology in Nuclear Power Plants

Moon Kyoung Choi [a], Poong Hyun Seong [a*]

[a]*Department of Nuclear and Quantum Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Korea*

[*]Corresponding author: stsk9107@kaist.ac.kr

INTRODUCTION

Over the past 20 years, about 20% of all nuclear plant events have been caused by human errors. The reduction of the accidents caused by human error is essential to improve the safe operation of safety-critical systems such as aviation and nuclear systems [1] [2].

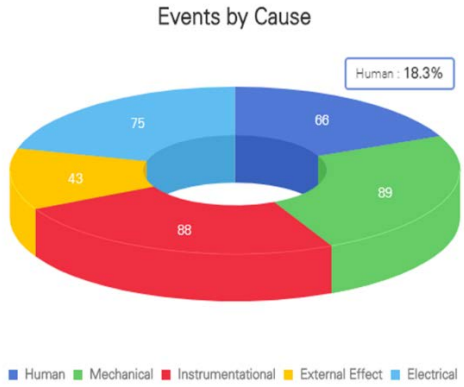

Fig 1. NPPs events by cause in recent 20 years (1997~2017) (From "opis.kaist.ac.kr")

One of the main factor contributing to human error is fatigue. Fatigue degrades human performance. The degree to which fatigue affects an individual can range from slight to catastrophic. Fatigue has been claimed as the primary cause of many major accidents [3]. For example, the incidents of Bhopal, Exxon Valdez, Three Mile Island, and Chernobyl list fatigue as a root cause [4]. However, it almost focused on the interface design such as HMI (Human Machine Interface), not individual factors at the Final Safety Analysis Report (FSAR) chapter 18, Human Factors, in the licensing process [5]. So, U.S. Nuclear Regulatory Commission (U.S. NRC) judged that fatigue is an important factor leading to human errors, and developed 'Managing Fatigue' of 10 CFR 26 presented as requirements to control operator fatigue in NPPs for improving the task efficiency and preventing human errors.

It is necessary to judge the fatigue of the operator and evaluate the fitness for duty before performing works.

SELECTION OF A METHOD FOR MEASURING FATIGUE & STRESS: EYE TRACKING SYSTEM

According to US-NRC, there are three types of measurement and estimation methods [6].

1) Biochemical Tests and Physiological and Behavioral Sensor Systems (EEG analysis, Eye tracking data analysis, Speech sound and pattern analysis, etc.)
2) Expert Observer Ratings (Behavioral Observation)
3) Self-Assessments (Stanford Sleepiness Scale, Swedish Occupational Fatigue Inventory, etc.)

In general, it is recommended to measure fatigue by the objective measurements in company with the subjective measurements.

TABLE I. COMPARISON OF BIO-SIGNAL MEASUREMENT

Measurement	Types	Non-invasive	Unaffecting operators' tasks	Simple and easy method	Reasonable accuracy
EEG	Bio electric signals	o	x	x	o
Eye tracking	Bio mechanical signals	o	o	o	o
GSR	Bio impedance signals	o	x	△	o
Skin temperature	Bio optical signals	o	o	o	x

EXPERIMENTAL DESIGN

1) The Purpose of Experiments

To provide a method to evaluate the fitness for duty of an operator by measuring eye tracking and cognitive performance data according to various fatigue of the operator

2) Experimental Environment & Equipments

Compact Nuclear Simulator (CNS) & Tobii Pro X3-120 Eye tracker (120Hz) were used for these experiments.

3) Test Subjects & Scenario

Total number of test subjects is 40 and they are majoring in nuclear engineering in KAIST. People feeling from slight to severe fatigue were test subjects. 'Pressurizer Safety Valve (SV) stuck open' scenario was selected to simulate the similar circumstance with TMI accident scenario.

4) Measured Data

① Saccadic Movement Data (Saccade Index, Saccadic Amplitude, Absolute Saccadic Direction, Relative Saccadic Direction)

② Eye Fixation Data (Fixation Index, Fixation count, Visit count, Fixation Duration, Visit Duration, Percent fixation on AOIs)

③ Subjective Symptoms of Fatigue Test: The test is given with a checklist designed by the

Industrial Fatigue Research Committee of the Japanese Association of Industrial Health. It consists of total 30 questionnaires). The maximum score is 150 that means the subjects feel extreme fatigue.

④ Accuracy of Information Acquisition about AOIs

5) Experiment Process

-Test subjects do self-assessment of their fatigue by using subjective fatigue questionnaire before conducting experiments.

-Test subjects have enough time to get familiar with the simulation screen and the location of the instrument in advance of experiments.

-Test subjects conduct calibration tests.

-'Pressurizer Safety Valve (SV) stuck open' malfunction is inserted in a simulator, and test subjects monitor the information on MMI screen for 100 seconds

-Test subjects check change of indicators on checklist, and then they diagnose the malfunctions according to information they gathered during experiments.

-Test subjects do self-assessment of their fatigue again after experiments.

ANALYSIS & RESULTS

Various data from test subjects that feel from slight to extreme fatigue was gotten through experiments mentioned above. In order to suggest the methodology that can evaluate the certain subject's fitness for duty, data clustering techniques were used. K-means clustering technique was used for data clustering. k-means clustering is a method of vector quantization, originally from signal processing, that is popular for cluster analysis in data mining. k-means clustering aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean, serving as a prototype of the cluster. This results in a partitioning of the data space into Voronoi cells.

The method is strong in terms of fast and efficient analysis. However, it has the weakness that the number of clusters should be determined in advance. Thus, the Elbow Method is used for choosing the optimal number of clusters before k-means clustering. The Elbow method is a method of interpretation and validation of consistency within cluster analysis designed to help finding the appropriate number of clusters in a dataset [7].

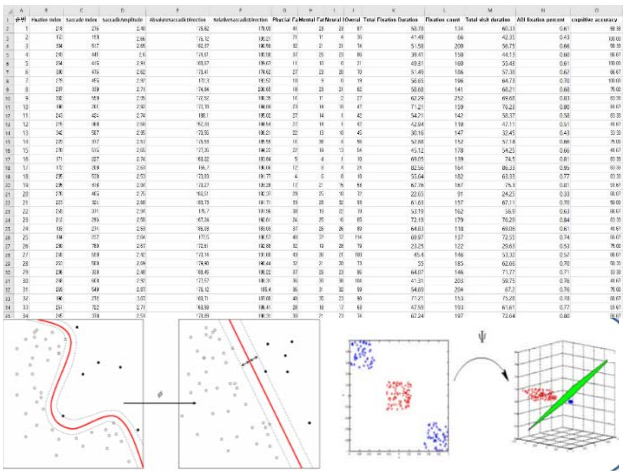

Fig 2. K-means clustering of participant's data

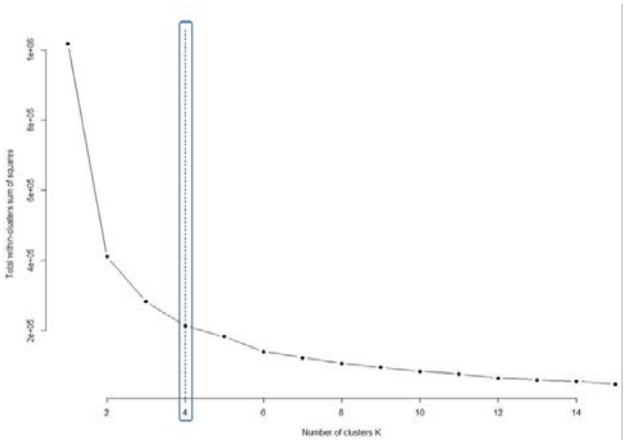

Fig 3. Selection of optimal number of clusters by Elbow method

It is determined that four clusters are optimal for our data sets to clustering analysis. Based on this result, k-means clustering analysis was conducted.

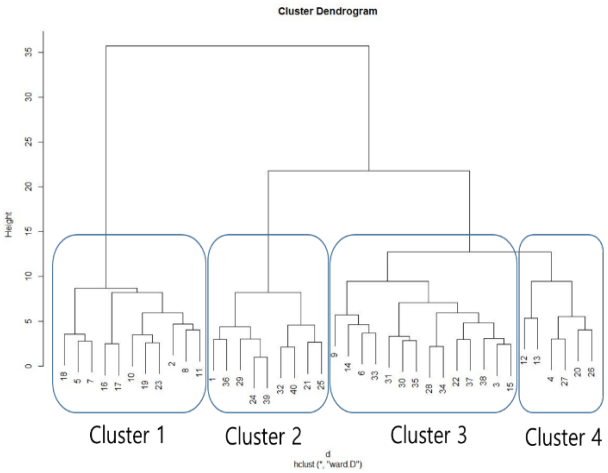

Fig 4. The results of k-means clustering analysis

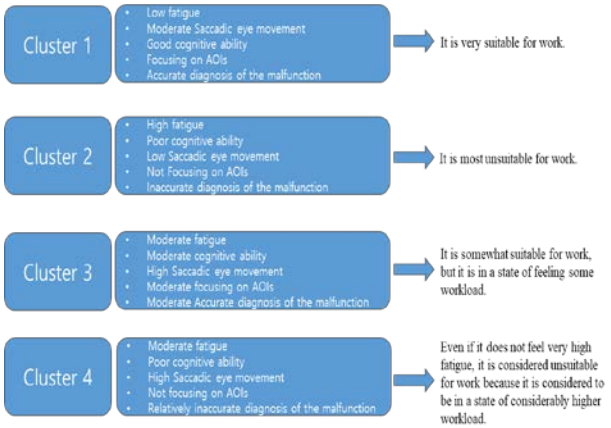

Fig 5. The Characteristics of clusters

It is determined that cluster 1 is very suitable for work due to low fatigue, moderate saccadic eye movement, good cognitive ability, well focusing on AOIs, and accurate diagnosis of the malfunction. Cluster 2 is the most unsuitable for work. If the fitness for duty evaluation result of the certain operator is classified to cluster 2, the operator is very unsuitable for work so the operator should take a rest and need to care their status. Cluster 3 is somewhat suitable for work, but it is in a state of feeling some workload because of moderate fatigue, moderate cognitive ability, high saccadic eye movement, moderate focusing on AOIs, and moderate accurate diagnosis of the malfunction. Cluster 4 is considered unsuitable for work because it is considered to be in a state of considerably higher workload even if it does not feel very high fatigue.

The fitness for duty evaluation methodology is proposed. However, this evaluation methodology should not generate or cause additional fatigue to operators. Thus, effect of the experiment on operator's fatigue was analyzed. A statistical t-test was used to assess whether there was a significant difference between the pre-test and post-test fatigue scores of the subjects. As the P-value was measured to be greater than 0.05, this experiment did not affect the fatigue of the subjects. It is statistically approved that the fitness for duty evaluating experiment does not affect an operator's fatigue.

CONCLUSION

One of the main factor contributing to human error is fatigue. Fatigue degrades human performance. The degree to which fatigue affects an individual can range from slight to catastrophic. It is necessary to judge the fatigue of the operator and evaluate the fitness for duty before performing works.

We scrutinized methodologies of measuring human performance and correlation analysis of bio-signals and human performance. US-NRC has been focusing on drug and alcohol testing and fatigue management. Most factors which affecting human performance are caused by fatigue in terms of fitness for duty. In addition, drugs intake of operator is considered rare in safety critical system operations. In this study, we dealt with measurement of fatigue (physiological indicators and their measurement, physical/behavioral indicators and their measurement, and cognitive and affective indicators and their measurement) only. In addition, fatigue-related technologies were surveyed. US-NRC said eye tracker is the most common method of measuring fatigue in terms of fitness for duty.

We will statistically analyze the eye tracking data of the subjects with varying degrees of fatigue to find a suitable state for nuclear power plant operations. We will also analyze the eye tracking data of highly stressed or stressed subjects to find out what is not suitable for the works of the plant and suggest ways to present it in advance. It is expected that this fitness for duty evaluation methodology can prevent human errors caused by high fatigue, and it can improve the NPPs safety in not only Korea but also UAE.

ACKNOWLEDGEMENTS

This research was supported by the 2018 KUSTAR-KAIST institute, Korea, under the R&D program supervised by KAIST.

REFERENCES

[1] DaeHo Kim, 'A Measurement of Safety Management Considering Physical and Mental Characteristic for Pilots,' Ergonomics Society of Korea, Vol. 11, pp. 324-330, 2005.
[2] OPIS, operational performance information system for nuclear power plant, http://opis.kins.re.kr/opis?act=KROBA3400R, 2015.07.23
[3] CANDICE D. GRIFFITH, SANKARAN MAHADEVAN, "Sleep Deprivation Effect on Human Performance: A Meta-Analaysis Approach", *Proc. Int. Conf. PSAM8*, KyeongJu, May 2006, INL/CON-06-01264
[4] Reason, J., 1990, Human Error, Cambridge University Press, Cambridge, England.
[5] Oh Yeon Ju et al, "A Study on Fatigue Measurement of Operators for Human Error Prevention in NPPs, Transaction of the Korean Nuclear Society Autumn Meeting, October 2012
[6] USNRC Regulatory commission, "Regulatory Guide 5.73; Fatigue management for nuclear power plant personnel", 2009
[7] David J. Ketchen Jr; Christopher L. Shook (1996). "The application of cluster analysis in Strategic Management Research: An analysis and critique". Strategic Management Journal.17 (6): 441–458.