E3S Web of Conferences 245, 03018 (2021) https://doi.org/10.1051/e3sconf/202124503018
AEECS 2021

Modeling digital main control room operator's resilience under extreme conditions: An Experiment design scheme

WEN Hanguan[1], Xu Zhihui[2], Xue Ke[1], and Jiang Chenyu[1], Yang Ming[1*]

[1]School of Electric Power Engineering, South China University of Technology, 510640 Guangzhou, Guangdong Province, China
[2] State Key Laboratory of Nuclear Power Safety Monitoring Technology and Equipment, China Nuclear Power Engineering Co., Ltd., 518172 Shenzhen, Guangdong Province, China

Abstract. Human reliability is one of the most important factors that make effects in nuclear power plant(NPP) operation. In advanced digital NPP main control room with high levels of automation, the systematic operation which require a sufficient mental workload to address those undesired events has become a critical challenge for operators. The aim of this research is to identify the operator's reliability by developing a resilience model. In this work, a seven-stage technique framework is proposed, which includes the skeleton of theoretical analysis, experimental design and hardware setting to how to establish the model for NPP operator in a downsize main control room cabin. The resilience model for operators' reliability via assessing their basic skill tasks performance and evaluating their cognitive workload in the framework hence can be used for assessing the level of training of the new employed operators as well as human reliability in other critical process industries.

1 Introduction

With the constant advances in automation technologies, modern advanced digital Nuclear Power Plant(NPP) main control room with high levels of automation, undesired accidents and events have a crucial effect on the systematic processing results. Operators working in main control room are playing an important role in the full-process of NPP operation particularly in the nuclear reactor which contains magnanimous radioactive substance which is the most sensitive part in the NPP system[1]. It is urgent to study main control room operator's reliability for sake of avoiding system faults due to his or her errors or unsafe actions. Therefore, human reliability should be put at the first place in study ensuring NPP's system safety. Human reliability[2] is an important aspect of any industrial processing or human-computer interaction field, indicating the amount of correctly to fulfill procedures(or actions) in the value or values reported[3]. There are lots of fertilizer in studying human reliability with the development of industrial processing to minimize the human errors that can be avoided[4]. The assessment process with task performance is the key indicator for studying industrial system operational strew especially some works that are dominated by operator or skill-oriented employees. Additionally, considering the relationship between human cognition and abnormal conditions particularly under the extreme temperature and humidity, various study fields and experiment studies have been conducted to reveal human reliability by studying on experimental participants' brain signals collected from electroencephalogram(EEG) by related sign detective devices in neurophysiological feature during simulated workplace scenes with different thermal-moist environment[5]. Indoor environment conditions are the a key factor that can impact operator's performance especially the temperature and humidity which may dominate the human ability in productivity[6-8]. To understand how do indoor environment conditions affect on human performance, cognition and psychology, developing approaches to evaluate human performance in changing even extreme indoor environment conditions have become a research tropic that bear significant human reliability and industrial processing stability. With the type of accounting the tolerance of a system, resilience is an academic term in industrial engineering and critical infrastructures since Holling's definition, and he specifying the term as 'the capacity to absorb or withstand perturbations such that the system remain within the same regime'[9]. Generally, resilience primarily defines systems' robustness, recovery ability and as its critical component(s) among the industrial processing and critical human-computing interface[10-12]. To sum up, studying quantify resilience as a function to reveal the capacity of a system that withstand those perturbations from the outside of the system is a adequate research way to modeling human reliability under abnormal disturbances from systemic outside.

In this work, therefore, we propose a technique framework in modeling operators' resilience under extreme environmental conditions with several detailed steps, and the framework which includes decomposed actions & match basic skills, reconstructed performance

* Corresponding author: moonhangest@126.com

task actions combination, collecting participants' EEG, establishing an extreme environment, modeling performance assessment, modeling cognitive evaluation, and Modeling operator's resilience. Also, we hope that the model for NPP's operators can be used for assessing the level of training of the new employed operators as well as human reliability in other critical process industries.

2 The technique scheme

A seven-stage technique framework is proposed in this study that demonstrates how to establish a resilience assessment model for NPP operators in downsize main control room. As shown in Fig.1, the first stage is decomposing actions and matching basic human work skills. Second, by reconstructing operators' tasks actions in main control room, a combination of performing tasks are reconstructed as the subjective indicators for modeling operator performance assessment in the experiment. The third stage is to collect participants' EEG as the objective indicators for modeling operator cognitive evaluation. In next step, we will build a downscale full-scope simulation cabin which can simulate the NPP main control room operating conditions and offering abnormal environmental events. Then, the data of participants who take part in operators' tasks of performance assessment are collected and operators' performance will be determined. After that, operators' cognitive evaluation will be studied. Finally, operator's resilience model is determined according to former steps above.

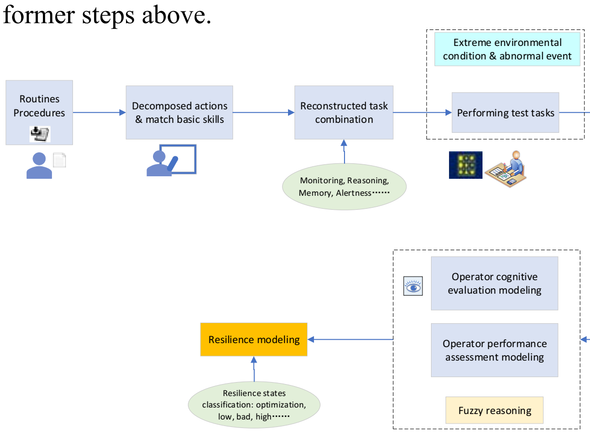

Fig.1. The outline of modeling operator's resilience

2.1 Stage1: decomposed actions & match basic skills

Basic testing skills should be derived from the real scenarios of the operator's performing actions. In the beginning, from the micro to macro perspective, the stage can be divided into two substeps: collecting the mainly NPP control room routines procedures as well identifying operators' actions, and decomposing those actions to basic skills associated with Fleischmann Job Analysis System.

Collecting operator's actions. Because main control room is the center control unit like a human brain in NPP, there are lots of procedures related to the whole system. In this work, we have studied some typical operator's routine procedures in main control room especially those are relevant to nuclear reactors' abnormal events based on a Chinese type Pressurized Water Reactor NPP as the sources of testing actions. According to historical data and documentaries, Steam Generator Tube Rupture(SGTR) is one of the most high-frequency abnormal events in NPP reactor operation, and the event operating procedure include main actions standing for operator's actions during abnormal conditions. Therefore, the procedure in dealing with SGTR should be considered as the first place to collect operator's actions, and then, the operator's routines procedure can be divided into discrete basic work skills.

Decomposing actions. To decompose normatively the routines procedure, the Fleishman Job Analysis System[13] is taken to apply, which is a discrete analytical approach in person's intellectual productivity demonstrating associated with employee's fifty-two mental work ability elements such as oral comprehension, written comprehension, memory capacity, deductive reasoning ability and inductive reasoning ability etc. Then, we had a consultation of our previous work to five experts who have been working long period in NPP main control room systematic ergonomic as well as sufficient analysis knowledge in human-machine interference field. Also, we had referred to relate previous literatures including Nuclear Regulatory Commission files[14,15], which are concerned in human factor and performance evaluation. Combine those judgments from these experts' advice along with historical events operating procedures in the NPP mentioned above, as a result, we conclude fourteen intellectual productivity work skills, shown in Table 1, and these basic discrete skills can on behalf of operators' principal actions.

Table 1. Basic discrete skills.

Memory	Written comprehension	oral comprehension
Information ranking ability	Coherence in ideas	Numerical reasoning ability
Near vision	Perceive problems	Numerical computing ability
Control deviation	Comprehension speed	Deductive reasoning
Selective attention	Inductive reasoning	

2.2 Stage2: reconstructed performance task actions combination

Once the basic discrete skills of NPP main control room operator have been identified, we have the raw materials to establish the test combination of operators' performing task for their resilience appraisal under extreme condition. Considering the requirement of high ecological validity in the experimental scenarios, we reconstructed a new task actions combination for specific operators. Table 2 shows the details of this combination which include the test tasks items and each item's discrete skills that can mapping to the Table 1. Those task actions include SGTR1 event, Memory in flashing tables, Numbers filling, Addition calculation and Word ordering, which have a higher executability.

Table 2. Task actions and mapping skills.

Task actions	Mapping skills
SGTR1 event	Comprehension speed & Control deviation & Memory & Near vision
Memory in flashing tables	Memory & Written comprehension & Selective attention
Numbers filling	Numerical reasoning ability & Deductive reasoning & Inductive reasoning
Addition calculation	Numerical computing ability & Oral comprehension & Coherence in ideas
Word ordering	Written comprehension &Information ranking ability& Perceive problems

2.3. Stage3: collect participants' EEG

We will plan to recruit student operators to participate in the action tasks test above, and collect their EEG data simultaneously. A Neurosky's Mindwave(NeuroSky Inc. 2020 ,San Jose, CA, USA) 64-channel EEG system(sampling rate at 512 Hz) will should be applied in the objective assessment. As step 2, these task actions test operators not only take their basic mapping skills but also collect their neurophysiological signals. For instance, the SGTR1 event is an accident naming Steam Generator Tube Rupture, which can drive the evolution of the steam generator from a normal state into an abnormal situation, which can become a significant evident to those student operators when alerts occur reply to equipment disturbances. And then, these trigger those student operators towards real-time data and gathering system information. After the data has been obtained, operators will implement a series of cognitive mental work such as analyzing fault mechanism, diagnosing error fault factor, matching mental logics to process conditions and taking response actions. Therefore, those operators will generate their electrical activity signals in microvolts with respect to the earlobe set as reference, and those participant's mental work raw EEG data will be recorded in 64-channel EEG system at 512Hz sampling frequency. The related further study will be discussed in Sect.2.6.

2.4 Stage4: establish an extreme environment

After theoretical scheming, we will build a downscale full-scope simulation chamber with controllable extreme environment parameter. Besides the general hardware design of the cabin, in our study work, here we design two modules in heat and moisture for adjusting the temperature and humidity in the whole cabin. In this study, the skeleton of the experiment facilities is conducted with dimensions of 5m x 4m x 3m at South China University of Technology in Guangzhou, China(Fig.2), where is a typical subtropical hot and humid region and strongly similar with those NPP where are located in the South Part of China such as Yangjiang NPP, Fangchengang NPP, et al.

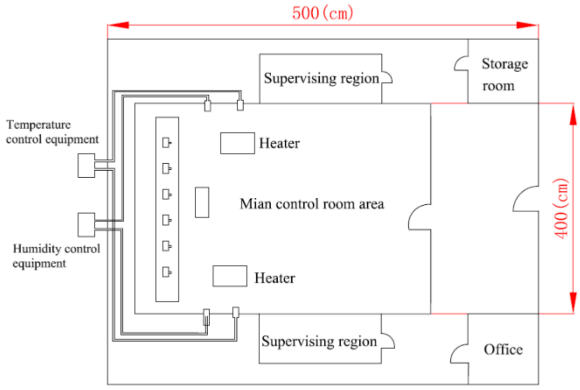

Fig.2. Experimental site design drawings

In the phase of extreme parameters selected, we refer to relevant documents among Chinese standards[16], American Society for Testing and Materials(ASTM) guidelines[17] and common hot and humid in-doors in subtropical climates[18]. Therefore, an orthogonal testing combination is created, shown in Fig.3.

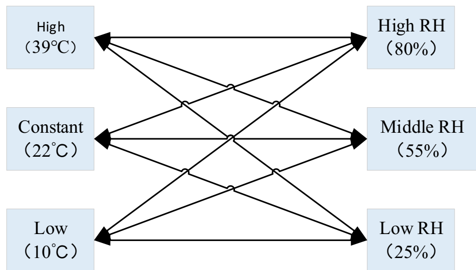

Fig.3. Orthogonal testing combination

Here the high temperature 39℃ was chosen as an extreme high temperature and the 22℃ as well as the 10℃ as the constant and low temperature according to the ASTM's document mentioned above. On the other hand, the determination of relative humidity(RH) selecting are based on Long-term records in subtropical regions[19].

2.5 Stage5: modelling performance assessment

Once the data of operators participating in performance experiments are obtained, we will quantify those operators' performance by performing fuzzy inference algorithm which is one of the most commonly use machine learning algorithms for sake of reasoning some blurred or subjective judgements more objective and corrective. In this study, we propose an updating fuzzy inference algorithm for modeling performance assessment, shown Fig.4.

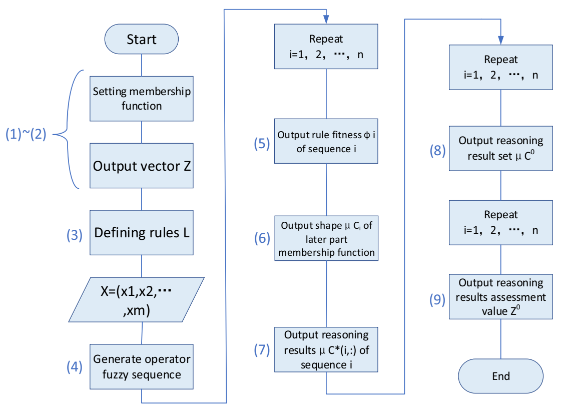

Fig.4. An updating fuzzy inference for determining operators' performance

Because in Fig.4 where those symbols are very basic-known in fuzzy inference and the limit of the paper space, we are focusing on some steps' detail that are important to the modeling process. In step 6 in Fig.5, after determining the membership functions by using fuzzy if-then rules, inputs and output of later fuzzy sets were determined as following equations:

$$\mu^0_{Low} = \begin{cases} 1-2|z| & \left(if\ |z| \le \frac{1}{2}\right) \\ 0 & \left(if\ |z| > \frac{1}{2}\right) \end{cases} \quad (1)$$

$$\mu^0_{Middle} = \begin{cases} 1-2\left|z-\frac{1}{2}\right| & \left(if\ \left|z-\frac{1}{2}\right| \le \frac{1}{2}\right) \\ 0 & \left(if\ \left|z-\frac{1}{2}\right| > \frac{1}{2}\right) \end{cases} \quad (2)$$

$$\mu^0_{High} = \begin{cases} 1-2|z-1| & \left(if\ |z-1| \le \frac{1}{2}\right) \\ 0 & \left(if\ |z-1| > \frac{1}{2}\right) \end{cases} \quad (3)$$

Where, μ^0 is the assessment set of later membership function, while z is the estimate value of operator's performance by the center of gravity defuzzification method, and the shapes of those Eq above are drawn in Fig.5. In next work, we will discuss the evaluation of participants' cognition through the study of their EEG data.

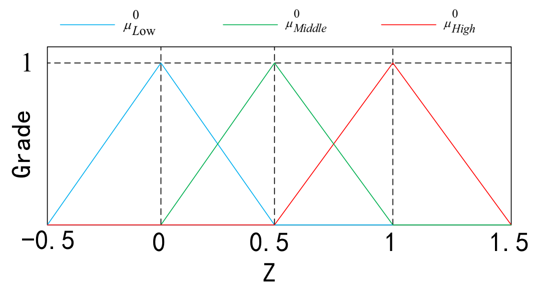

Fig.5. Shape of later membership functions

2.6 Stage6: modeling cognitive evaluation

At the same time, along with processing their performance appraisals, we are also going to study participants' cognitive evaluation by using MATLAB's EEGLAB toolbox to analyze their raw EEG data for sake of the resilience model. In this part, the data will be processed associated with time-frequency transform and calculating power spectral density(PSD). Moreover, we can study at PSD's fluctuation to determine those operators' cognitive workload by using MATLAB's EEGLAB toolbox[20], shown in Fig.6.

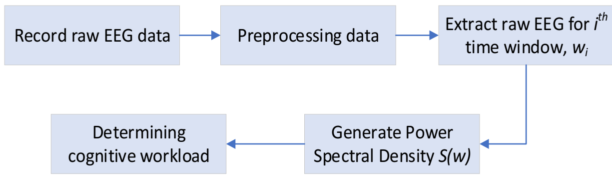

Fig.6. The flow chart of determining cognitive workload

Where, w_i in Fig.6 is the time window in time i which is the results that raw EEG value are segmented into various sliding time windows to obtain the average PSD for sake of minimizing the artefacts effect of the raw EEG. In the flow chart, it is inevitable that the recording data from participants and should be preprocessed such as missing data, data error et, because that preprocessing data is a key procedure for ensuring the quality of data analysis for the final accuracy of the cognitive evaluation. Similar to modeling performance assessment, we will build a quantitative model for identifying participants' cognitive workload via fuzzy reasoning method. In this model, three cognitive levels including high, middle and low are proposed with an interval(0,1) in fuzzy inference algorithm as mentioned in Fig.5.

2.7 Modeling operator's resilience

As shown in Fig.7, combining the participants' basic skills performance with their cognitive evaluation, a model approach for NPP operator's resilience is constructed. In the model, we have developed four categories including 'Low', 'Terrible', 'High' and 'Optimistic' for revealing operators resilience under the extreme environmental conditions.

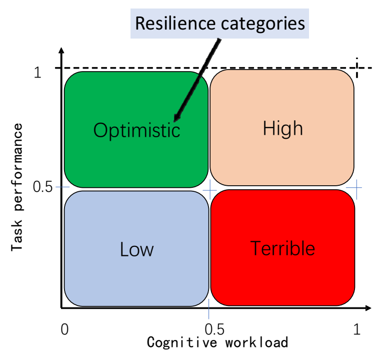

Fig.7. The approach of modeling operator's resilience

When an operator take an interval (0, 0.5) to cognitive workload along with same interval to task performance, his/her resilience assessment should be identified at the category 'Low', while category 'Terrible' is occurred if his/her take an interval (0.5, 1) to cognitive workload and (0, 0.5) to task performance, then the 'High' will be defined as the operator get an interval (0.5, 1) in cognitive workload as well as the same interval level to task performance. The last category, however, when an operator's cognitive workload is under (0, 0.5) and the interval of task performance is (0.5, 1), we can entitle it with 'Optimistic'. With the contribution of the resilience model, we can study those operators working in NPP main control room how to effectively treat some undesired uncertainties in the systemic operation with their professional expertise including the routine procedures and basic neurophysiological situations.

3 Discussion and conclusion

In this paper, we propose a novel technic framework whose basic methodology is to capture the performance of basic skill tasks as well as abnormal operating events and EEG's cognitive workload to identify operator's resilience under extreme environmental conditions. This identification of resilience levels 'Low', 'Terrible', 'High', 'Optimistic' are important as it results in the operator handling abnormal pressure both physical and mental fields, which in turn influences human reliability in NPP.

The proposed technic framework can be utilized to improve the overall reliability and resilience of main control room operators in several ways. The proposed approach can be used in providing information about the resilience of operators during training term. This design can be utilized to assess the level of training of the new recruited operators. Also, the framework of studying resilience to improve human reliability in other process industries can be explored, thus will create a new paradigm to the human reliability.

4 Future work

In this paper, our work is concentrating on the state of designing framework for studying operator's resilience under extreme environmental conditions, which have included theorical analysis, pervious related literature and the details in modelling in operator resilience in section 1. However, it is unreliable for the framework without the realistic experiment. Therefore, in our future work, we will execute the detail protocols of the framework in this paper, and also, we will apply the results in these research fields in human reliability analysis in NPP.

Acknowledgement

The study is supported by Guangdong Basic and Applied Basic Research Foundation under Grant 2019A1515111124 and 2019B1515120060.

References

1. Benish R, Smidts C, Aurand A, Gupta GJ, Boring R. A pilot experiment for science-based human reliability analysis validation. In: Proceedings of the probabilistic safety assessment and analysis (PSA 2013). Columbia, SC; 2013.
2. Kirwan B. Human error identification in human reliability assessment. Part 1: overview of approaches. Appl Ergon 1992;**23(5):299–318**.
3. James CY, Bley D, Criscione L, Kirwan B, Mosleh A, Madary T, et al. The SACADA database for human reliability and human performance. Reliab Eng Syst Saf 2014;**125:117–33**.
4. Groth KM, Mosleh A. A data-informed PIF hierarchy for model-based humanreliability analysis. Reliab Eng Syst Saf 2012;1**08:154–74**.
5. Cohen, M.X. , 2014. *Analyzing Neural Time Series Data: Theory and Practice*. MIT press .
6. D. Clements-Croome, *Creating the productive workplace*: Taylor & Francis, 2006.
7. L. Lan, Z. Lian, L. Pan, and Q. Ye, "Neurobehavioral approach for evaluation of office workers' productivity: The effects of room temperature," Building and Environment, vol. 44, pp. **1578-1588**, 2009.
8. P. Wargocki, "Productivity and health effects of high indoor air quality," in Encyclopedia of environmental health, ed: Burlington: Elsevier., 2011.
9. Holling CS. Resilience and stability of ecological systems. Annual review of ecology and systematics 1973;**4(1):1–23**.
10. Faturechi R, Miller-Hooks E. Travel time resilience of roadway networks under disaster. Transportation research part B: methodological 2014;**70:47–64**.
11. Francis R, Bekera B. A metric and frameworks for resilience analysis of engineered and infrastructure systems. Reliability Engineering & System Safety 2014;**121: 90–103**.
12. Nan C, Sansavini G. A quantitative method for assessing resilience of interdependent infrastructures. Reliability Engineering & System Safety 2017;**157: 35–53**.
13. E.Fleishman and M. Reilly: *Handbook of Human Abilities*, Consulting Psychologists Press, pp.**1-37**,(1992).
14. Barriere, M., et al. *"Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)"* NUREG-1624, Rev. 1. U.S. Nuclear Regulatory Commission, Washington, DC, 2005. May 2000
15. Erasmia Lois, M., etal.*"The Employment of Empirical Data and Bayesian Methods in Human Reliability Analysis: A Feasibility Study"* NUREG/CR-6949. U.S. Nuclear Regulatory Commission, Washington, DC, September 2005.
16. Ministry of Housing and Urban-Rural Development of the People's Republic of China. *Design Code for Heating Ventilation and Air Conditioning of Civil Buildings: GB50736*. Beijing, China: China Architecture & Building Press; 2012.

https://doi.org/10.1051/e3sconf/202124503018

17. American Society for Testing and Materials (ASTM). *Standard F2668–07: Determining the Physiological Responses of the Wearer to Protective Clothing Ensembles*. West Conshohocken, PA: American Society for Testing and Materials (ASTM); 2011.
18. Yamtraipat N, Khedari J, Hirunlabh J. Thermal comfort standards for air conditioned buildings in hot and humid Thailand considering additional factors of acclimatization and education level. Sol Energy. 2005;**78(4):504-517**.
19. Jin L, Zhang YF, Zhang ZJ. Human responses to high humidity in elevated temperatures for people in hot-humid climates. Build Environ.2017;**114:257-266**.
20. Delorme, A., Makeig, S. (2004). EEGLAB: an Open Source Toolbox for Analysis of Single-Trial EEG Dynamics.