An Unsafe Act Autodetection Methodology in Nuclear Power Plant Operations

Jeeyea Ahn, Jae Min Kim, and Seung Jun Lee(✉)

Ulsan National Institute of Science and Technology, 50, UNIST-gil,
Ulsan 44919, Republic of Korea
{jeeya, jaemink, sjlee420}@unist.ac.kr

Abstract. Nowadays, automation has been generalized with artificial intelligences in many areas. In nuclear power plants, some features which have simple logics in nuclear power plants such as reactor trip and engineered safety features (ESFs) actuation have been automated, whereas, other components have not been automated yet, so human operators are still necessary to control the reactor in emergency or abnormal situations. However, there exists a risk of human errors since human operators are involved in nuclear power operations. That is because, human error may contribute to the risk of severe accidents. To reduce those human errors, moreover, to draw to extend the portion of automation in nuclear power plants, a framework which automatically detects Unsafe Acts (UAs) which are occurred in advanced main control rooms of nuclear power plants has been introduced. Human operators are supposed to operate nuclear power plants by following operating procedures. However, in real operational situation, they violate operating procedures sometimes to achieve the goal (to keep the plant integrity) based on their own experiences and their know-hows. Critical safety functions (CSFs) can disentangle whether an operator's action will adversely affect plant integrity. Thus, the UA autodetection system considers both procedure violation and CSFs violation to find out errors made by human operator.

Keywords: Unsafe act · Autodetection · Nuclear power plant operation

1 Instruction

As modern technology enters the Fourth Industrial Revolution, Modern artificial intelligence techniques are very pervasive. In some cases, artificial intelligence replaces human tasks (i.e. autonomous vehicle) or supports human performances (i.e. online assistants such as Siri and Bixby). As technologies support human, human workload may decrease, so that human performance and efficiency would be increased, and the probability of human error would be decreased.

Nuclear power has the limelight since it generates clean and economic energy. However, the severe accident in nuclear power plant might bring terrible consequences. The risk of nuclear power plant must manage strictly. Because of that characteristics, technologies which apply to the nuclear industry are appraised very precisely and conservatively.

C. Stephanidis (Ed.): HCII Posters 2018, CCIS 850, pp. 333–339, 2018.
https://doi.org/10.1007/978-3-319-92270-6_48

Nuclear industry is one of the fields which human-factor may significantly affect the risk of severe disaster. In fact, the most of severe accidents (e.g. Three Miles Island, Chernobyl Accidents) in nuclear power plants have been occurred on account of human-factor failures, namely human errors. Thus, a lot of researchers who are involved in this nuclear area have been trying to eliminate those human errors entirely. Thanks to the efforts, in nuclear power plants, some features which have simple logics such as reactor trip and engineered safety features (ESFs) actuation have been automated. However, other components have not been automated yet, so human operators are still necessary to control the reactor in emergency or abnormal situations. Since human operators are still involved in nuclear power operations, there remains a risk of human errors.

In advanced main control rooms of nuclear power plants, computerized procedures are implemented instead of paper procedures which used to be employed in conventional main control rooms. Applying computer-based procedures in the main control room allows to reduce mental workload, enhance situation awareness, and produce lower errors of omission than paper-based procedures [1]. The number of human errors in nuclear power plant operation may decrease thanks to the computerized procedure system (CPS). However, new types of human errors are being considered which may occur [2].

In this paper, we propose a framework which automatically detects Unsafe Acts (UAs) which are occurred in advanced main control rooms in nuclear power plant to reduce those human errors, moreover, to draw to extend the portion of automation in nuclear power plants.

2 Background Information

2.1 Unsafe Acts

Unsafe actions are actions inappropriately taken by plant personnel, or not taken when needed, that result in a degraded plant safety condition [3]. Nuclear power plant operation is proceduralized to reduce mental workload of human operators. Human operators basically follow operating procedures. An action which does not follow the operating procedure, the action may adversely affect nuclear power plant integrity. In this case, the action will be a candidate of UAs. Human operators of nuclear power plants work for a plant for a long time by its nature. Some operators who have a lot of experiences and know-hows in nuclear power plant operation. Sometimes, the seasoned operators decide what they will do in different way than operating procedures. They perform the steps which they believe more important earlier, they run different devices than what procedures instruct to control the system. Not all these violations negatively affect integrity of the nuclear power plant. Another mean or criterion is required to distinct UAs that would harm the plant integrity among the candidates of UAs.

2.2 Critical Safety Functions

Critical safety functions are a group of actions that prevent core melt or minimize radiation releases to the general public. They can be used to provide a hierarchy of practical plant protection that an operator should use [4]. The functions designed to protect against core melt, preserve containment integrity, and maintain vital auxiliaries needed to support the other safety functions are identified (Table 1). These safety functions show plant safety statements, so parameters included in the functions will indicate if the plant integrity is adversely affected in practice.

Table 1. Classification of critical safety functions

Anti-core melt
– Reactivity control – Reactor cooling system (RCS) inventory control – RCS pressure control – RCS heat removal – Core heat removal
Containment integrity
– Containment isolation – Containment pressure control – Containment temperature control – Combustible gas control
Maintain vital auxiliaries
– Vital power maintenance

2.3 Nuclear Simulator

After Three Mile Island and Chernobyl accidents, it has come out into the open that operator errors contribute to extend and progress of severe accidents in nuclear power plants. The importance of training using simulators has increased sharply [5].

Generally, training simulators for nuclear power plants are classified into three categories: compact or basic principle simulator, full-scope simulator, part-task simulator. Compact or basic-principle simulator is intended to illustrate general concepts and demonstrate and display of the fundamental physical processes of a plant. Full-scope simulator is more complete and accurate simulator describing the whole plant and system. Part-task simulator is designed for a single specific system functionally divided from a whole plant [6]. The UA autodetecting system can be developed by using nuclear simulator to generating AI training data sets and verify the system. We used CNS which is a compact nuclear simulator developed by Korea Atomic Energy Research Institute (KAERI). The CNS modeled a three loop Westinghouse Pressurizer Water Reactor (PWR), 993 MWe, mostly referred to as the Kori Unit 3&4 in Korea (Fig. 1).

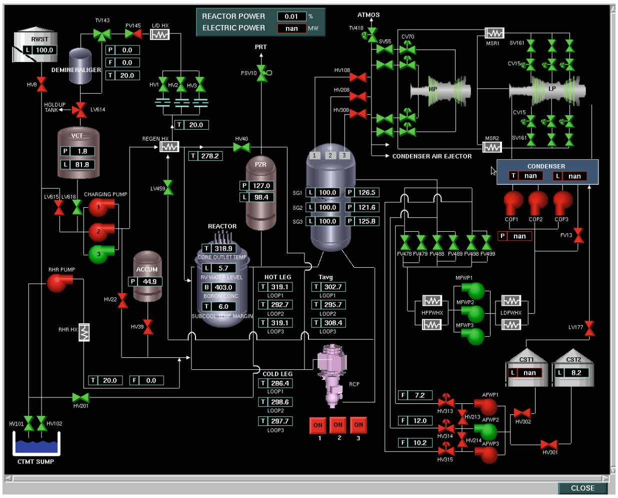

Fig. 1. The compact nuclear simulator (CNS), 993 MWe PWR

3 Unsafe Acts Autodetection Framework

The UA auto-detecting process basically has three steps (Fig. 2).

I. Procedure Violation Check
II. Evaluation of the Effect on Critical Safety Functions
III. Recovery Operation Suggestion

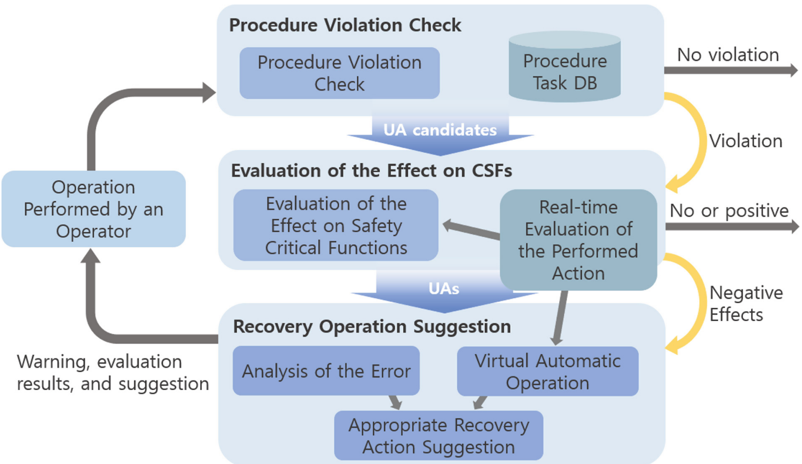

Fig. 2. Unsafe acts autodetection framework

In the first step, the system checks procedure compliance. It judges which tasks in an instruction are required to be performed or not, and whether an action performed by an operator complies the operating procedure. If not, the action will be classified as a UA candidate. In the next step, the effect on critical safety functions of the UA candidate is evaluated. When negative effects are expected, the UA candidate is set to be a UA. Then, the system gives a warning to the operator with evaluation results and suggests a recovery operation. The operator can recognize his/her mistake and restore it quickly with the information given by the system.

3.1 Procedure Violation Check

To check procedure compliance, procedure task database is needed. The procedure task database includes all tasks prescribed in operating procedures corresponding to each state. The tasks in procedures can be categorized into four types, Information verification, procedure transfer, situation evaluation and execution [7] (Table 2).

Table 2. The classification scheme of erroneous behaviors

Category	Proceduralized task	Description examples in EOPs
Information verification	Verifying alarm occurrence	Determine a turbine trip alarm
	Verifying state of indicator	Verify that one reactor coolant pump is running
	Synthetically verifying information	Verify if safety injection completion conditions are satisfied
	Reading simple value	Read the charging pump flow rate
	Comparing parameter	Verify if the pressurizer level is within 25–35%
	Comparing using graph constraint	Check if the reactor coolant system subcooling margin is within the subcooling operation area on the attached graph
	Comparing for abnormality	Check if the containment vessel is in an adverse state
	Evaluating trend	Check if the pressurizer level is stable
Procedure transfer	Transferring procedure	Perform the diagnostic procedure
	Transferring step in procedure	Go to step 22.0
Situation evaluation	Diagnosing	Investigate the cause of a pressurizer relief valve abnormality
	Identifying overall status	Evaluate the necessity of plant cooling
	Predicting	Evaluate the long-term plant status

(*continued*)

Table 2. (*continued*)

Category	Proceduralized task	Description examples in EOPs
Execution	Manipulating simple (discrete) control	Close the steam bypass control valve
	Manipulating simple (continuous) control	Establish the set point of the steam generator power operated relief valve at 81.5 kg/cm^2
	Manipulating dynamically	Discharge steam to the condenser using the turbine bypass valve
	Notifying/requesting to MCR outside	Stop the reactor coolant pump using a field breaker

3.2 Evaluation of the Effects on Critical Safety Functions

To evaluate the effect on safety critical functions, waiting for change in parameters related to the functions takes time, so it would be too late to cope with the situation. Artificial intelligent training can be a solution. A trained artificial intelligence with operating history can predict trends of the changes derived by operators' actions. However, the states which require to use emergency operating procedures are rarely happened in real nuclear power plant operation, so operators practice emergency operations using simulators. Training data from operating history can be generated based on plenty of operating scenarios by using a nuclear simulator.

3.3 Recovery Operation Suggestion

When UAs are detected, recovery operation guide will be provided. In this step, the trained AI suggests the best option to cope with the UA. In the virtual plant, an optimize operation is running automatically, and the operation will be shown to the human operator who made the UA. Before showing, error analysis should be conducted.

4 Discussion and Conclusions

In this work, a framework which identifies unsafe acts of plant personnel in nuclear power plant is suggested. To begin with, actions which violate operating procedures are classified as UA candidates. Then, the expected trends of parameters related to critical safety functions sort out UA from the candidates. If the identified UAs are noticed to the human operator in nuclear power plants, he/she will be able to cope with the errors made by themselves speedily. To expect the trends, a AI algorithm and database should be built. If training data corresponding to various operating actions for different operating circumstances are collected based on the framework, plenty of data can be produced which are required to analyze human errors for the new digitalized system in nuclear power plants. Furthermore, this framework and database can be a base to control all safety critical functions simultaneously using an automated system. It would us to take a step toward making the operating system be fully digitalized and automated.

References

1. Yang, C.-W., Yang, L.-C., Cheng, T.-C., Jou, Y.-T., Chiou, S.-W.: Assessing mental workload and situation awareness in the evaluation of computerized procedures in the main control room. Nuclear Eng. Des. **250**, 713–719 (2012)
2. Min, D., Chun, Y.-H., Kim, B.: An evaluation of computerized procedure system in nuclear power plant. IFAC Proc. **34**(16), 519–524 (2001)
3. U.S. NRC: Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA), NUREG-1624 (2000)
4. William, R.C., Nancy, J.P., James, F.C., Michael, T.C., Walter, M.G.: The critical safety functions and plant operation. Nuclear Technol. **55**(3), 690–712 (1981). https://doi.org/10.13182/nt81-a32814
5. U.S. NRC: TMI-2 Lessons Learned Task Force Final Report, NUREG-0585 (1979)
6. Kwqn, K.-C., Park, J.-C., Jung, C.-H., Lee, J.-S., Kim, J.-Y.: Compact nuclear simulator and its upgrade plan. Training simulators in nuclear power plants: experience, programme design and assessment methodology. In: Proceedings of a specialists' meeting, p. 227. International Atomic Energy Agency (1997)
7. Kim, Y., Park, J., Jung, W.: A classification scheme of erroneous behaviors for human error probability estimations based on simulator data. Reliabil. Eng. Syst. Safety **163**, 1–13 (2017)