Development of the Support Tool Preventing Violations in Nuclear Power Plants

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***Abstract*— The aim of this study is to develop guidelines and the support tool for preventing violations in nuclear power plants and to evaluate the effects of developed support tool. Nuclear industry needs ways to prevent violations, which is one of human errors. Human error is the major reason of nuclear accidents which result in a global impact. For fundamental and effective prevention of human errors, approach by types of human errors is needed. For idea generation, morphological analysis and brainstorming were conducted. Guidelines were used as one factor of morphological analysis for support tool idea generation. Six high scored ideas of support tool functions in feasibility were developed into smart safety helmet. Effects of developed smart safety helmet were evaluated through interview and survey. Participants responded positively in usability and effectiveness. The result of this study can be used for preventing violations in nuclear power plants. Also it is applicable to various industry where workers wear a safety helmet.**

Keywords-violations; nuclear power plant; prevention; support tool; guidelines; safety helmet;

I. INTRODUCTION

The accident at a nuclear power plant is very rare [1]; however, it can lead severe damage [2]. The results of the nuclear accident are not only death of workers and neighborhood residents, but also contamination of soil and water. Neighboring countries can also suffer from the radiation leakage issues [3]. Typological approach of accident causes is needed to find effective ways preventing nuclear accidents.

Human error is one of the reasons of nuclear accident. It is usually classified under 'slips and lapses', 'mistakes', and 'violation' [4]. This study focuses on 'violation' because research about 'slips and lapses' and 'mistakes' is relatively popular [5][6][7]. For example, Itoh et al [8] considered only slips and mistakes for understanding of internal mechanisms on a man-machine interface used by nuclear power plant operators. Also, Yun and Lee [9] evaluated only safety of smart mobile from slips or mistakes of workers in nuclear power plants.

Although research about violations is not popular, basic research about violation was carried out through defining violation based on failure analyses [10] and classifying types of violations [11]. However, the practical approach is necessary for preventing violations because present violation prevention methods such as campaign and posters are limited to activate workers. One of the practical approach is the support tool based on Internet Of Things(IoT). IoT can collect workers' information through sensors and give feedback on their work behavior. Also, IoT can lead hands-free communication among workers so it could catch their violation and make them stop to do violation. Moreover, IoT support tools enable workers to communicate each other and check progress of task frequently. Thus, data from IoT devices can be used for current violation analysis and personalized task suggestion. Accordingly, IoT can make smart workplace of the nuclear power plant.

Therefore, this study developed guidelines and the support tool preventing violations in nuclear power plants and evaluated the effects of the support tool. This research focused on routine violations. Routine violation can be happened more frequently than other types of violation in nuclear power plants. To generate ideas of guidelines and support tool, morphological analysis(MA) and brainstorming were used. Support tool is mainly for operators and test/repair workers who are work at the coalface.

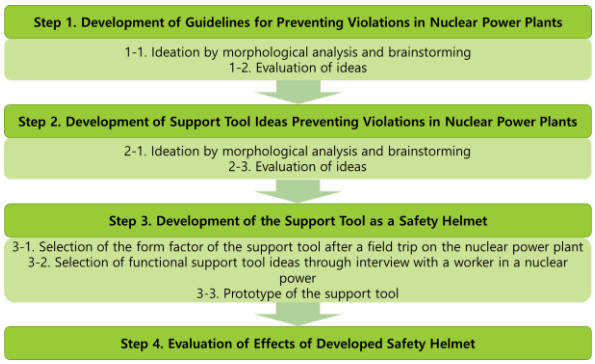

Figure 1. Research process

The research process is shown as Figure 1. This paper explains the study step-by-step.

II. DEVELOPMENT OF GUIDELINES FOR PREVENTING VIOLATIONS IN NUCLEAR POWER PLANTS

First, three user experience(UX) engineering experts developed the guideline ideas for preventing routine violations in nuclear power plants. They used MA and brainstorming for idea generation.

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A. *Ideation by morphological analysis and brainstorming*

MA is one of idea generation tools by combining factors which stimulate ideas. This method is effective when generating ideas for solving problems because as many as possible number of cases can be considered [12][13]. The factors used for achieving guideline ideas are three; organization-related violation characteristics, occurring mechanisms of routine violation, and job types. Kang et al. [10], which is a prior study founded organization-related characteristics(OC) and occurring mechanisms of routine violation.

In this study, OC which is composed of 11 factors about operation of organization/safety and 3 factors in education/training and 3 occurring mechanisms of routine violation were combined. After that, possible combinations and three job types in the nuclear power plant were combined to generate ideas.

Additionally, experts conducted brainstorming based on the causes and definition of routine violation. Consequently, total 58 ideas were derived.

B. *Evaluation of ideas*

Three UX experts evaluated ideas using 3-point Likert scale based on the viability and suitability. Poor ideas were ruled out and then 30 ideas were derived.

These ideas were developed as guidelines. One example of guidelines is “design interface in workspace through worker-centric ergonomic design to conduct tasks according to manual easily”.

III. DEVELOPMENT OF SUPPORT TOOL IDEAS PREVENTING VIOLATIONS IN NUCLEAR POWER PLANTS

A. *Ideation by morphological analysis and brainstorming*

Three UX engineering experts chose the three factors for MA; form factor of support tools, types of support functions, and guidelines in section 2. Support tool ideas were derived by combining these three factors.

The form factor of support tools means device or tool such as smartphone/tablet, safety helmet, and big display to realize functional ideas. Also, the types of support function refers to functional role of the idea such as provision of information, monitoring/feedback, and reporting system. The 20 form factors of support tools and 6 types of support function were collected from the literature about preventing human error in various fields such as information and communication and safety engineering and industrial fields such as construction, shipbuilding, and chemistry.

Guidelines for preventing violations are the result of section 2. Similar guidelines in 30 guidelines were merged into 8 guidelines. Then, this eight guidelines were used in MA.

For efficient process of support tool idea generation, the form factor of support tools was combined with support function. Then, 67 possible combinations between them were combined with guidelines. 74 ideas were deducted from MA.

Brainstorming was additionally conducted to supplement ideas. Violation occurrence situations were derived and classified as cue in brainstorming session. 13 situations were drawn from analysis of 27 representative cases of nuclear accidents in Republic of Korea by human error since 2005. Furthermore, seven situations were extracted from industrial accidents by human error in recent five years. Based on these 20 situations, researchers brainstormed 16 ideas.

B. *Evaluation of ideas*

Researchers evaluated ideas by feasibility. Feasibility means how easy the idea be realized technically. This is because ideas which can be conducted a spot inspection should be prototyped. Three UX experts assessed ideas using 5-point Likert scale. Ideas over 3.5 average points in feasibility were selected.

IV. DEVELOPMENT OF THE SUPPORT TOOL AS A SAFETY HELMET

A. *Selection of the form factor of the support tool after a field trip on the nuclear power plant*

The ideas which were generated using one specific form factor can be matched with other form factors. For example, the idea; “The support tool gives warning to the cofactors when they becomes far away from each other” was derived based on a wearable band. However, this idea can be applied to other form factors such as safety helmet, smartphone/tablet, and emergency beeper. For that reason, the ideas were matched with all possible form factors thorough discussion.

To select the form factor of the support tool, researchers visited the nuclear power plant. After the field trip, safety helmet was selected as the form factor of the support tool. This is because safety helmet is existing protect equipment. Accordingly, workers would feel less burdensome than other form factors such as wearable band and emergency beeper. Also, workers should wear the safety helmet in workplace in nuclear power plants. Therefore, applicable place is more various than other form factors such as large displays and smartphone/tablet.

B. *Selection of functional support tool ideas through the interview with a worker in a nuclear power plant*

Interview with a worker in the nuclear power plant was conducted to consider viability of functional ideas of the safety helmet.

Based on the interview, researchers exclude functions which already existent and are unnecessary. In case of ideas related to wireless communications, interviewee said that they were hard to be applied because of technological problem such as interference. However, technological problem could be solved after the technological developments naturally. Therefore, we included ideas which cannot be applied because of technology. Selected functional ideas are shown in Table 1.

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TABLE I. SELECTED FUNCTIONAL SUPPORT TOOL IDEAS

Types of Functional Ideas	Functional Ideas
Management of wearing a safety helmet	• Turn on/off of the safety helmet when a worker contacts the safety helmet to a terminal on entrance/exits • Warning 10 seconds after when a worker takes off the safety helmet • Providing voice message about safety when a worker wears/takes off the safety helmet • Sensing health information of a worker through sensors in the safety helmet and providing the information for health care
Communication aid	• Communication with workers within certain distance • Communication with workers in certain workplace • One to one communication • Communication between a supervisor and a worker periodically for checking attention to work
Assistance in Maintaining of distance among workers	• Warning if workers are too far apart for maintaining distance among them during cooperation work

C. *Prototype of the support tool*

Selected of functional support tool ideas realized in form of the safety helmet(Figure 2, Figure 3). It has sensors on the forehead part and headset. Display which shows health information was made.

Figure 2. Prototype of the support tool(Safety helmet)

Figure 3. Prototype of the support tool(Terminal)

TABLE II. FUNCTIONS OF THE SUPPORT TOOL

Types of Functions	Functions
Management of wearing a safety helmet	• Warning and providing messages about safety when a worker does not wear the safety helmet during 10 seconds • Warning and providing messages about safety when a chin strap comes untied
Wireless communication	• Communication with a cooperator • Communication between a director and a worker
Assistance in Maintaining of distance among workers	• Warning if the distance among workers over 10 meters
Health care	• Providing health information such as heart rate and oxygen saturation when a worker contact the safety helmet to the terminal on entrance/exit

Functions were refined as Table 2 because of time and cost.

V. EVALUATION OF EFFECTS OF DEVELOPED SAFETY HELMET

The experiment including interview and survey was conducted to evaluate effects of the prototype of the support tool. Eight workers participated and they wear a safety helmet during working in the nuclear power plant. Their work experience is over one year. The average of work experience is 5.69 years and standard deviation(s.d.) is 4.28 years. They are all male and their average age is 37.38 and s.d. of age is 7.67.

The experiment was progressed as Fig. 4. Subjects listened to explanation about the support tool and then operated it himself for understanding. In the interview, they said pros and cons of functions of the support tool freely based on experience in the previous stage. Also they should try all functions again. Therefore, they could consider usability and effectiveness of preventing violations. After the interview, the survey was conducted. The survey was composed of questions about usability and effectiveness of violation preventive functions. Participants answered in 5-point Likert scale. Detail questions in the survey are shown in Table 3.

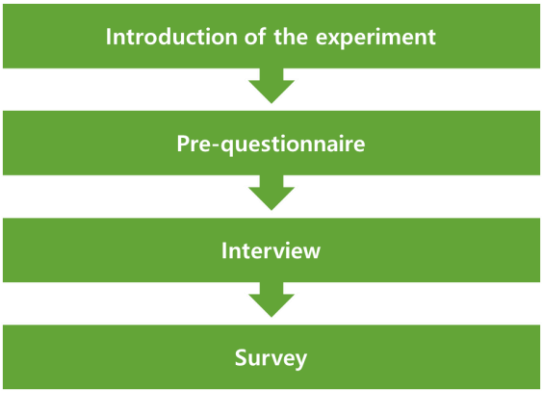

Figure 4. Process of the experiment

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TABLE III. CONTENTS OF SURVEY

Question No.	*Description*
1	The sound of warning messages to wear a safety helmet is clearly heard.
2	Warning messages to wear a safety helmet will reduce cases that a worker does not wear a safety helmet.
3	The way to check health information of the worker such as heart rate and oxygen saturation is easy to learn and memorize.
4	A worker can check his/her health information such as heart rate and oxygen saturation clearly on the display.
5	A worker can check his/her health information such as heart rate and oxygen saturation easily and quickly on the display.
6	Health care function can induce workers to wear a safety helmet.
7	The sound of warning messages to maintain distance among workers is clearly heard.
8	Warning messages to maintain distance among workers will reduce cases that a worker works individually during cooperative work.
9	The way to use voice communication function is easy to learn and memorize.
10	Information about status of voice communication function is clearly provided.
11	A worker can use voice communication function easily and quickly.
12	Voice communication function can reduce cases of not checking working status between a work director and a field worker.
13	The sound of voice messages before/after the work is clearly heard.
14	Voice messages before/after the work can raise safety consciousness.
15	This safety helmet will reduce violations which happen routinely such as not wearing a safety helmet, unchecking work status, and working individually during cooperative work.

The results of the survey are shown in Figure 5 and Figure 6. Almost every participant agreed that the developed safety helmet prevents violations. Also everyone said that health care function can lead workers to wear the safety helmet except one participant who answered “disagree”. Therefore, this support tool is expected to reduce violations.

Participants responded positively to usability questionnaires. There is no negative answer in whole questions about usability. Thus, it means that people can use the prototype of the support tool without great difficulty.

Considerations to improve the support tool were extracted from the results of the interview. There were total 22 considerations. Among them, considerations which are mentioned by more than two participants are shown in Table 4. Improvement proposals came up based on subjects’ opinions in the interview and discussion between two UX engineers.

Improvement proposals related to functions were drawn. In case of health care function, providing more detail health information in real time would be better. In case of assistance function to maintain a certain distance among workers, distance set up function is needed because keeping distance among workers would be different depending on task types. Also, workers should be able to turn off the function maintaining distance if a task does not need to keep a certain distance. Communication among all collaborative

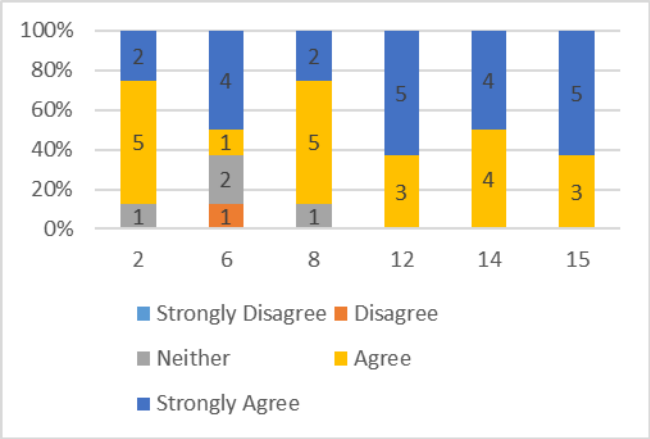

Figure 5. The freqeuncy of response by evaluation questions – Possibility of preventing violations

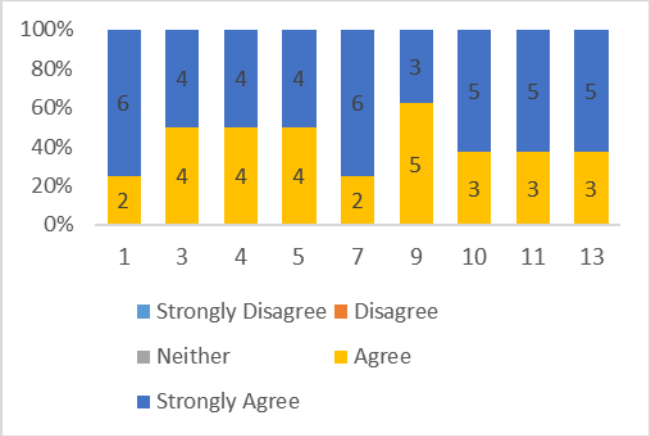

Figure 6. The freqeuncy of response by evaluation questions – Usability

TABLE IV. THE FREQUENCY OF CONSIDERATIONS FOR IMPROVEMENT

Considerations for Improvement	*Related Function/Design Factor*	*Frequency*
A lot sweat	Headset	5
Short distance for maintaining	Assistance in Maintaining of distance among workers	4
Difficulty in binding a chin strap	Chin strap	2
Impossibility of providing health information in real time	Health care	2
No turn off button of assistance in maintaining of distance among workers	Assistance in Maintaining of distance among workers	2
Undue pressure	Headset	2
Heaviness	Safety helmet	2

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workers would be better than one-to-one communication. Moreover, process of changing communications target should be easier.

Improvement proposals related to design elements were generated. Location of the switch should be changed to the site where a worker does not press the switch by mistake. Otherwise, it would be better to make the power of the support tool be turned on or off automatically when a worker goes in or out the workplace. A form of earphone is also recommended. This is because earphone arrest noise enough and more convenient for workers in the workplace which does not product noise a lot. Wearing recognition should be moved to optimal position where it can sense well. Optimal position could achieve through the ergonomic experiments.

In other researches about development of a safety helmet to prevent safety accident, there are some possible improvement proposals. Jang et al. [14] made check system for wearing a safety helmet with wireless sensor network. This system logs whether a worker wears a safety helmet or not through sensor module at chin strap in real time. Therefore, it aids a work director to check wearing condition easily and quickly. Providing information and warning about safety helmet wearing condition to both a worker and a work director would be better. Also, data from logging safety helmet wearing condition can be used to analyze violations.

Hong et al. [15] developed the safety helmet with alarm bell to prevent safety accident. They said that the alarm bell rings when stress and heart rate from electrocardiogram(ECG) and brain wave sensors go over certain range. This safety helmet has similar function compared to health care function. However, this tracks health information and alarm in real time and uses different sensors. To provide various and helpful health information, ECG and brain wave sensors can be added.

In this study, support tool ideas were generated mainly based on guidelines about prior checking and task guidelines. Therefore, tracking data and collecting data were out of our research scope. However, tracking and storing health information and warning immediately such as safety helmets in Jang et al. [14] and Hong et al. [15] can be good health care function.

VI. CONCLUSION

In this study, guidelines and support tool ideas for preventing routine violations were generated using MA and brainstorming. Through visiting real nuclear power plant and interview, ideas were selected and developed to the functions of the support tool, safety helmet. After the development, the effects of this safety helmet were evaluated by workers who wear safety helmets during working in the nuclear power plant. As a result, the safety helmet is not difficult to use and good for preventing violations such as not wearing helmet and rare communication.

The developed safety helmet will prevent not wearing safety helmet and performing alone during cooperative work. Moreover, communication support function induces workers to converse actively and smoothly so every task can go according to plan. Also this support tool could be applied to other industries where workers wear safety helmets. Additionally, guidelines and developed support tool help workers in nuclear power plants cultivate safety consciousness. If the safety helmet will be designed with consideration for comfort, more workers will try to wear the safety helmet. Also, violations because of not wearing a safety helmet will decrease a lot.

People in nuclear industry tend to avoid talk about violations because violation receives negative attention in the society. Accordingly, it was hard to recruit workers as participants and collect their ideas and experience. This is because various opinions of workers were not reflected in idea generation and development of the support tool.

Currently, the wireless communication technology is difficult to be applied in nuclear power plants because of interference. After solving that problem and developing various support tool based on IoT, a nuclear power plant can be a smart workplace.

Therefore, more ideas for preventing violations could be generated by collaboration with workers in nuclear power plants later. Additionally, various form of support tool could be developed besides the safety helmet. Thus, this methodical approach could be applied to study other violations.

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