Comparing the operators' behavior in conducting emergency operating procedures with the complexity of procedural steps

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Abstract

Many kinds of procedures have been used to reduce the operators' workload throughout various industries. However, significant portion of accidents or incidents was caused by procedure related human errors that are originated from non-compliance of procedures.

According to related studies, several important factors for non-compliance behavior have been identified, and one if them is the complexity of procedures. This means that comparing the change of the operators' behavior with the complexity of procedures may be meaningful for investigating plausible reasons for the operators' non-compliance behavior.

In this study, emergency training records were collected using a full scope simulator in order to obtain data related to the operators' non-compliance behavior. And then, collected data are compared with the complexity of procedural steps. As the result, two remarkable relationships are found, which indicate that the operators' behavior could be reasonably characterized by the complexity of procedural steps. Thus, these relationships can be used as meaningful clues not only to scrutinize the reason of non-compliance behavior but also to suggest appropriate remedies for the reduction of non-compliance behavior that can result in procedure related human errors.

1. Introduction

With industries becoming more complicated, various activities (such as process automation or computerization) have been attempted to reduce the operators' workload [1-3]. As one of them, the provision of appropriate procedures has been emphasized in many industries [1, 2, 4]. In the nuclear industry, for example, procedures have been emphasized to secure the safety, since not only one of the important legacies from the Three Mile Island (TMI) accident is the reformation of emergency operating procedures (EOPs) [1], but also it has been reported that most accidents that actually occurred could have been effectively

coped with through EOPs [5].

It is remarkable that, however, significant portion of accidents (including incidents) was caused by procedure related human errors (such as omitting important actions) due to the non-compliance of procedures (i.e., did not carry out procedures in accordance with written instructions) [6]. Thus, to maximize the safety, it may be requisite to understand the reason why the operators do not follow procedures as written.

Many useful insights that can be used to identify plausible factors for non-compliance behavior have been stated from related studies. As a result, one of the typical factors is identified as the complexity of procedures. This means that comparing the change of the operators' behavior with respect to the complexity of procedures could be reasonable starting points to scrutinize the operators' non-compliance behavior.

In this study, thus, to obtain data related to the operators' non-compliance behavior, emergency training records were collected using a full scope simulator installed in the training center of the reference nuclear power plant (NPP). After that, three types of the SROs' (senior reactor operators) behavior observed from these records, such as strict adherence, skipping redundant actions and modifying action sequences, were compared with the SC (step complexity) scores that can represent the complexity of procedures [7-9].

This paper is organized as follows. At first, in order to manifest the direction and the objective of this study, important factors related to non-compliance behavior are investigated based on several rationales deduced from literatures. As the next, types of the SROs' non-compliance behavior observed from emergency training records are briefly described with the reason why the SROs' behavior has to be stressed for scrutinizing non-compliance of EOPs. And then, as the results of this study, two kinds of relationships obtained from comparing the SROs' non-compliance behavior with the complexity of procedural steps are provided. Finally, discussions related to these results are given in order to support the conclusion of this study.

2. Factors for non-compliance behavior

There are several rationales that give useful insights for explaining the reason why the operators frequently do not follow procedures as written [6]. From these rationales, important factors that make the operators difficult in obtaining what they want from procedures can be identified from two different viewpoints [10]. That is: 1) the deficiencies of procedures (i.e., inaccurate or incomplete procedures), and 2) the complexity of procedures.

Between these viewpoints, however, the complexity of procedures seems to be more important for understanding of non-compliance behavior, since a huge amount of effort has been made to prevent problems originated from deficient procedures. For example, in the case of nuclear industry, many guidelines or checklists have been used to investigate the suitableness of EOPs [11]. In addition, although much more time-consuming activities may be needed, it is mandatory that "the validity of developed EOPs should be ensured through a mock-up test and walk-through." Thus, it can be assumed that problems related to deficient procedures could be properly identified through these activities.

Therefore, it may be meaningful to scrutinize the reason of procedural deviations through

the comparison of the operators' behavior (i.e., how the operators conduct procedures?) with the complexity of procedures. It is noted that, hereafter, the complexity of procedures will be referred by the complexity of procedural steps, since it was shown that the complexity of procedural steps can be considered as a 'basic' unit for evaluating the complexity of procedures [7] and that the SC measure could properly quantify the complexity of procedural steps originated from task demands implied by procedural steps [8, 9].

3. Data collection

To scrutinize the operators' non-compliance behavior, two kinds of information may be indispensable, such as: 1) types of the SROs' behavior to conduct procedures, and 2) the complexity of procedures. In other words, since the SROs play a leading role in conducting EOPs, the SROs' behavior may be decisive to consider non-compliance behavior. To understand this aspect more clearly, it may be helpful to review what is the mandatory process to conduct EOPs.

When emergency situations occurred, most of emergency operations in NPPs were performed by operating crews working in MCR (main control room), and several types of crew organizations have been usually adopted for emergency operations [12]. In case of the reference NPP, all required actions specified in procedural steps are performed based on the SRO's commands.

Under this operation scheme, it is clear that non-compliance of EOPs would be closely related to the SROs' behavior, since EOPs were principally conducted under the SROs' direction. In addition, it is expected that most burdens which may arise during conducting EOPs may be put on them [12]. This means that, to scrutinize non-compliance behavior related to EOPs, it is worth to compare types of the SROs' behavior with the complexity of procedural steps.

Based on this concern, a full scope simulator installed in the training center of the reference NPP was used to classify the SROs' behavior types. This full scope simulator is designed based on a 1000MWe PWR (pressurized water reactor) type NPP with conventional control panels and alarm tiles. In addition, since a set of video recording equipment was installed in the training center, all kinds of operators' activities occurred in MCR can be recorded on videotapes.

The record collection period was from September 1999 to July 2001. During this period, the total number of training scenarios was six, and they covered all design basis accidents (DBAs) of the reference NPP. Table 1 shows summarized information about collected emergency training records.

From these emergency training records, three types of the SROs' behavior were identified through protocol analyses, and they can be listed as follows.

- Type A (strict adherence): The SROs strictly followed a procedural step as written.
- Type B (skipping redundant actions): When the SROs entered a procedural step, they either skipped identical actions that are already conducted in the previous procedural step or conducted identical actions based on information what they already know.
- Type C (modifying action sequences): the SROs performed a procedural step using a

modified action sequence that is different from a predefined one.

< Table 1. Summaries for the collection of emergency training records >

Record collection period	Emergency training scenario	The number of collected records
Sep. 1999 ~ Dec. 1999	SGTR (steam generator tube rupture)	5
	LOAF (loss of all feedwater)	5
Jan. 2000 ~ Jul. 2000	LOCA (loss of coolant accident)	18
	ESDE (excess steam dump event)	18
Aug. 2000 ~ Dec. 2000	SGTR	18
	LOAF	18
Jan. 2001 ~ Apr. 2001	LOOP (loss of offsite power)	10
	SBO (station black out)	10
	LOCA	10

Based on the above classifications, 'Type A' represents compliance behavior. In contrast, both 'Type B' and 'Type C' imply non-compliance behavior because the SROs either skipped several actions or did not follow a predefined action sequence. Based on these classifications, the SROs' behavior to conduct, in total, 1062 procedural steps can be identified from collected emergency training records, and Table 2 shows summarized results for them.

< Table 2. Observed SROs' behavior types for conducting procedural steps >

	Type A	Type B	Type C	Total
Number of observations	787	62	213	1062
Percentage of occurrence	74.11	5.84	20.25	100.0

 4. The change of the SROs' behavior according to the complexity of procedural steps

To clarify the effect of the complexity of procedural steps on the SROs' behavior, SC (step complexity) scores were compared with the types of the SROs' behavior. This is because results from several studies indicated that the complexity of procedural steps originated from task demands implied by procedural steps could be properly quantified by the SC measure [7-9].

To compare SC scores and types of the SROs' behavior, observed data were grouped with respect to several arbitrary ranges of SC scores, and then performed c^2 test. Table 3 shows comparison results, and sum of occurrence percentages for non-compliance behavior was plotted in Fig. 1 with respect to the ranges of SC scores.

From the result of c^2 test in Table 3, it seems that the SROs' behavior could be affected by SC scores, since c^2 value is greater that the rejection criterion for the null hypothesis ($c^2 = 36.26 > c^2_{0.01}(6) = 22.46$). As denoted by the result of c^2 test, if the SROs' behavior could be affected by SC scores, then two noticeable relationships between non-compliance behavior and SC scores can be extracted.

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The first one is that "many SROs seem to adopt non-compliance behavior more frequently when they entered a procedural step which has an intermediate procedural complexity." In Fig. 1, the percentage of occurrence for non-compliance behavior is minimized at the SC scores ranging from 1.326 to 1.725. In contrast, when the SROs entered a procedural step that has either relatively low (i.e., SC scores under 1.325) or relatively high procedural complexity (i.e., SC scores over 1.726), most of them appear to follow a procedural step as written.

< Table 3. Comparison results between behavior types and the SC scores >

| SC scores	The number of operators[1]	Number of observations		
		Type A	Type B	Type C
Under 1.325	24	152 (140.1)[2]	20 (11.0)	17 (37.9)
1.326 ~ 1.725	24	403 (432.0)	33 (34.0)	147 (116.9)
1.726 ~ 2.125	23	173 (161.6)	7 (12.7)	38 (43.7)
Over 2.126	20	59 (53.4)	2 (4.2)	11 (14.4)
Total		787	62	213

1. For example, the value of 24 means in total 24 operators were performed procedural steps of which SC scores are less than 1.325.
2. Scores in parentheses mean expected cell frequencies (estimated values) to perform χ^2 test. The result is:
$\chi^2 = 36.26$; df = 6; p < 0.01; rejection criteria = $\chi^2_{0.01}(6) = 22.46$
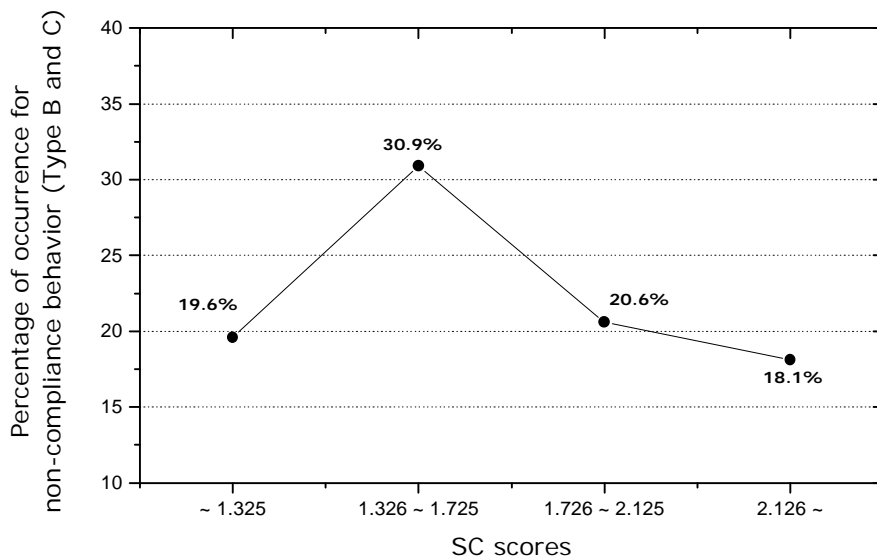
< Figure 1. The percentage of non-compliance behavior with respect to SC scores >

As for the second relationship, it can be observed that "the SROs seem to accommodate their non-compliance behavior to the complexity of procedural steps." To clarify this relationship, let consider Fig. 2 that shows the percentage of occurrence for both 'Type B'

and 'Type C' behavior, respectively.
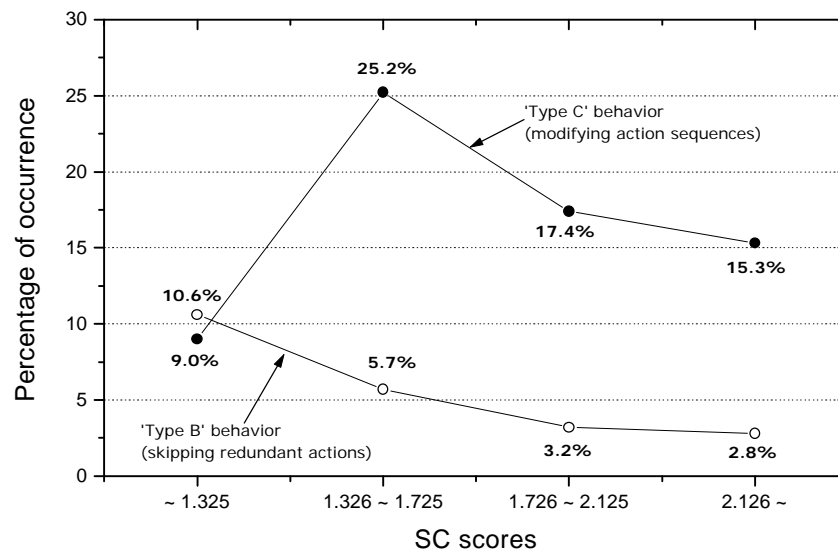
< Figure 2. Percentage for 'Type B' and 'Type C' behavior with respect to SC scores >

From Fig. 2, two distinctive features can be observed. The first one is that the SROs who conducted procedural steps through non-compliance behavior seem to evenly adopt 'Type B' and 'Type C' behavior, if a procedural step is relatively easy. Because, when the SROs entered procedural steps of which SC score are under 1.325, the percentage of occurrence for both 'skipping redundant actions' and 'modifying action sequences' are almost identical.

In contrast, as the second feature, most of non-compliance behavior done by the SROs are 'modifying action sequences,' when the SROs entered procedural steps that have relatively either an intermediate or high procedural complexity (say, SC scores over 1.326), since the percentage of occurrence for 'Type C' behavior is always larger (about five times) than those of 'Type B.'

5. Discussions and conclusion

Up to now, to scrutinize the reason of non-compliance behavior, three types of the SROs' behavior were compared with the complexity of procedural steps quantified by SC scores. As the results, two kinds of remarkable relationships are obtained. From these features, useful clues for disclosing the reason of non-compliance behavior could be acquired, since the SROs' behavior seems to be affected by the complexity of procedural steps.

For example, if the SROs confronted an easy procedural step, it was observed that most of them carried out it as written, since it can be assumed that "a procedural step is so easy that the SROs don't need to consider non-compliance behavior to shorten it." Similarly, in case of a complicated procedural step, the SROs also showed relatively high procedure compliance, since they might feel a burden shortening it. In contrast, in case of a procedural step that has an intermediate procedural complexity, it was observed that many SROs adopt non-compliance behavior to simplify it . And, this observation could be properly explained if the

assumption of "not only they can easily understand its context but also the outcome of adopting non-compliance behavior is quite obvious" is introduced.

In addition, if so, it is expected that these relationships would play a significant role not only to understand the reason of non-compliance behavior but also to suggest appropriate remedies to decrease frequencies of procedure related human errors.

Thus, it is hoped that relationships obtained from this study can be used as meaningful clues not only to scrutinize the reason of non-compliance behavior but also to suggest appropriate remedies for reducing procedure related human errors. For an example, one of the guidelines for checklist design, which was proposed from the aviation industry to enhance the operators' performance, is that "a long checklist should be subdivided into smaller checklists [4]." However, this guideline seems to be insufficient for real application if we cannot answer a critical question: "what is a 'long' checklist that make the operators trying to shorten?" In this case, it is expected that the SC measure could be used to identify a checklist which the operators are likely to shorten, since the operators' behavior seems to be changed by the complexity of procedural steps.

Although, many additional studies have to be performed to confirm the relationships between the operators' behavior and the complexity of procedural steps, the following simple and feasible conclusion can be drawn from this study.

Since the SROs' behavior seems to be reasonably characterized by the complexity of procedural steps, relationships obtained from this study can be used not only to scrutinize the reason of non-compliance behavior but also to suggest appropriate remedies for reducing non-compliance behavior that can result in procedure related human errors.

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