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A study on the validity of a task complexity measure for emergency operating procedures of nuclear power plants—Comparing task complexity scores with two sets of operator response time data obtained under a simulated SGTR

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Abstract

The appropriateness of the task complexity (TACOM) measure that can quantify the complexity of procedural tasks was validated in this study. To this end, two sets of task performance time data that have been extracted under the simulated steam generator tube rupture (SGTR) conditions of the reference nuclear power plant (NPP) A and B were compared with the associated TACOM scores. As a result, it was observed that two sets of task performance time data seem to be soundly explained by the associated TACOM scores. Although more additional activities should be conducted to clarify the appropriateness of the TACOM measure, the result of this study provides a crucial clue supporting that the complexity of emergency tasks stipulated in emergency operating procedures (EOPs) can be properly quantified by the TACOM measure.

Keywords: Task complexity measure; Operator performance; Simulated emergency; Emergency operating procedure

1. Introduction

Operating experiences have continuously emphasized that one of the determinants for the safety of large process systems is a reliable human performance [1–5]. As a consequence of extensive efforts, it is perceived that the use of procedures is one of the most serviceable countermeasures for ensuring a reliable human performance [4,6,7]. However, the use of procedures has the nature of a double-edged knife.

The bright side is that good procedures can effectively aid human operators at least in three ways:

- Procedures manifest what is to be done by operators (reducing physical and/or mental workload) [5,8,9].
- Procedures help operators to minimize the possibility of forgetting and/or skipping crucial actions (reducing the possibility of human errors) [10,11].
- Procedures allow operators to homogeneously maintain their performance that could be affected by a human variability (standardizing performance) [11–13].

In addition, procedures play a decisive role when operators have to accomplish their tasks under harsh environments, such as a severe time pressure or a stressful condition [14–16]. Accordingly, extensive efforts have been made to provide useful procedures that can successfully support human operators [17–21].

Ironically, it was revealed that the degradation of an operator's performance largely attributes to procedure-related problems [1,4,5,8,12,22–24]. In the light of procedures, this fact seems to be natural because procedures directly govern operators' cognitive as well as physical

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behavior by institutionalizing detailed actions [5,25–27]. In other words, an operator's performance could be impaired, if operators have to use inaccurate and/or incomplete procedures that give either wrong or obsolete instructions [4,8,28].

However, even when procedures provide accurate and complete instructions, an operator's performance could be drastically deteriorated by complicated procedures because of two reasons:

- Complicated procedures hinder operators from identifying what should be done, which have to be decided based on an on-going status [4,9,11,29,30].
- Complicated procedures distract operators from sub-tasks that are also critical to accomplish a given task [11,12].

To reduce the side effects of complicated procedures, therefore, a systematic approach that can properly evaluate the complexity of procedures is necessary.

From this necessity, Park and Jung have developed a task complexity measure called TACOM that consists of five sub-measures [31]. These sub-measures cover significant factors that can make the performance of emergency tasks included in emergency operating procedures (EOPs) of nuclear power plants (NPPs) complicated [32].

The TACOM measure was preliminarily validated by comparing the estimated TACOM scores with task performance time data that were obtained from emergency training sessions of a NPP (i.e., reference plant A) [31]. As a result, it is expected that the TACOM measure could be useful in quantifying the complexity of emergency tasks, since task performance time data were significantly correlated with the associated TACOM scores. However, this expectation seems to be premature because it has been believed that the performance of operators who conduct a well-defined task can be predictable as well as be standardized by the function of the complexity of tasks. In other words, since the preliminary validation just showed that task performance time data could be predictable with respect to TACOM scores, it is indispensable to investigate whether task performance time data could be soundly comparable with respect to TACOM scores. Thus, the aim of this study is to consolidate the appropriateness of the TACOM measure by clarifying that an operator's performance could be standardized when they conduct a well-defined task. To this end, task performance time data that were additionally gathered from another NPP (from hereafter referred to as the reference plant B) were compared those of the reference plant A.

The remaining part of this paper is organized as follows. In Section 2, background information about the development of the TACOM measure is briefly explained. After that, detailed processes for gathering additional task performance time data from the reference plant B are explained in Section 3. The result of this study is given in Section 4, and the conclusion of this study is drawn in Section 5 with discussions that justify the rightfulness of this study.

2. Background of the TACOM measure

As stated in Section 1, the virtue of procedures is to assist human operators. From this perspective, it may be helpful to concisely review the nature of procedures for the off-normal events of NPPs.

In the beginning, it was anticipated that most of the off-normal events could be successfully stabilized by carrying out chronological instructions as written in a step-by-step manner [33,34]. Related studies have accentuated, however, that carrying out emergency tasks stipulated in procedures is not a simple rule-following behavior but a very difficult problem-solving behavior that requires high-level cognitive activities and/or skills [11,30,35,36]. This is because operators have to continually consider "what is to be done" or "how to do it" from written instructions after comprehending the nature of an on-going situation with which they are faced. There are two rationales supporting this concern.

The first one is that the clarification of required actions could be harder than it seems because most people have a difficulty in understanding the contents of written instructions. For example, when a printed instruction is given, it was found that the people only understood two-thirds of its context [37]. This strongly indicates that the identification of proper actions along with the on-going situation demands additional cognitive activities [38].

The second rationale is that operators have to use 'static instructions' in order to cope with 'dynamic situations' that can be diversely varied as time passes [17,39], because it is very difficult for complicated process systems to create an omnipotent procedure that can reflect every situation [40]. As a result, additional high-level cognitive activities (such as a situation assessment) are needed to carry out procedures that could be interpreted differently according to the changes of an on-going situation [30,34,39,41].

In connection with these rationales, identifying significant factors that can make the performance of procedures complicated would be the most natural starting point to provide serviceable procedures. From this necessity, Park et al. identified five factors that could make the performance of emergency tasks complicated [32]. In addition, based on five complexity factors, five kinds of sub-measures were developed to quantify the complexity of emergency tasks included in EOPs. Table 1 summarizes the definition of all the five sub-measures [31].

It should be noted that all the sub-measures were calculated by the first- and the second-order graph entropies that have been used to quantify the complexity of software [42]. In order to calculate the first-order entropy, the distinctive classes of nodes should be identified based on their in- and out-degree as they appear in a graph. That is, if there are nodes that have the same in- and out-degree, then they are regarded as equivalent classes.