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Investigating the appropriateness of a decision chart to characterize the level of task descriptions in nuclear power plants

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A B S T R A C T

Traditionally, the use of operating procedures is very popular or even mandatory in large process control systems including nuclear power plants (NPPs), commercial airplanes and railway systems. This is because good procedures are very effective in enhancing the performance of human operators who have a responsibility for operating these systems. However, the improvement of an operational safety by providing procedures is meaningful only if human operators are able to properly access necessary information from them. In this regard, it is well known that one of the most significant factors affecting the proper use of procedures is the level of task descriptions, which is directly related to the provision of necessary information what human operators want to know. For this reason, in this study, the appropriateness of a decision chart that allows us to characterize the level of task descriptions is investigated using subjective difficulty scores collected from 98 human operators working in domestic NPPs. As a result, it was observed that there is a significant relation between the level of task descriptions and the subjective difficulty score of human operators. Therefore, it is reasonable to say that the decision chart can be regarded as a starting point to scrutinize the contribution of task description levels to the preparation of good procedure.

1. Introduction

There are many kinds of definitions that express the generic nature of an operating procedure. For example, Vanderhaegen (1999) and Wagner et al. (1996) stated that "*A procedure is a list of tasks to be performed in optimal functioning conditions (p. 1398)*" and "*A proceduralized instruction is a set of step-by-step instructions (a procedure) intended to ensure the successful completion of a task (p. 10-49)*," respectively. In addition, the Environmental Protection Agency (2001) denoted that "*A standard operating procedure (SOP) is a set of written instructions that document a routine or repetitive activity followed by an organization. The development and use of SOPs are an integral part of a successful quality system as it provides individuals with the information to perform a job properly, and facilitates consistency in the quality and integrity of a product or end-result (p. 1).*" From these statements, it is reasonable to say that an operating procedure consists of many steps including detailed descriptions that provide necessary information in conducting the required tasks safely and effectively. In this regard, Table 1 summarizes some of the potential benefits when operating procedures are used.

From the point of view of managing large process control systems, these benefits are essential because one of the dominant factors affecting their operational safety has been known as human performance related problems (e.g., human error) (Frostenson, 1995; HSE, 2005; Pyy et al., 2001; Taylor, 2000). In other words, if procedures are effective for enhancing the performance of human operators, then the provision of good procedures will be a practical way to reduce the risk of large process control systems (Brito, 2002; Dien et al., 1992; Hattermer-Apostel, 2001; Macwan and Mosleh, 1994; Salminen and Tallberg, 1996; Wieringa and Farkas, 1991). Actually, Degani et al. (1999) articulated this expectation by advocating such that: "*In complex human-machine systems, successful operations depend on an elaborate set of procedures provided to the human operators. These procedures specify a detailed step-by-step process for configuring the machine during the normal, abnormal*

Abbreviations and acronyms: CST, Condensate Storage Tank; DEG, Designated means; DETAIL, Detailed level description; EOP, Emergency Operating Procedure; gpm, Gallon per minute; INH, Inherent means; INTER, Intermediate level description; LO, Local Operation; MCR, Main Control Room; NC, No Criterion; NM, No Means; NPP, Nuclear Power Plant; OBJ, Objective criterion; PROB, Problematic level description; PRZ, Pressurizer; PWR, Pressurized Water Reactor; RCP, Reactor Coolant Pump; RCS, Reactor Coolant System; RI, Reference Information; SG, Steam Generator; SGTR, Steam Generator Tube Rupture; SI, Safety Injection; SME, Subject Matter Expert; SOP, Standard Operating Procedure; SRO, Senior Reactor Operator; SUB, Subjective criterion; TACOM, Task Complexity; UK, United Kingdom.

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Table 1
Potential benefits in using operating procedures.

Reference	Potential benefits
Environmental Protection Agency (2001)	• Providing detailed instructions that can be used as a part of a personnel training program • Minimizing opportunities for miscommunication • Reducing work effort
Health and Safety Executive (2004)	• Minimizing errors/failures • Protecting against the loss of operating knowledge (e.g., the retirement of experienced personnel) • Standardizing working practice • Providing a basis for training • Satisfying statutory requirements
Health and Safety Executive (2005)	• Good written procedures are vital in maintaining consistency and in ensuring that everyone has the same basic level of information • Procedures play a key role in ensuring that good quality training is delivered • Reliable and usable procedures are the key to avoiding 'mistake' type human error
De Carvalho (2006)	• Reducing complexity level by allowing activities to be accomplished by using IF-THEN rules • Reducing the probability of human errors
Frostenson (1995)	• Reducing workload • Reducing shortcuts evoked to complete job

and emergency situations. The adequacy of these procedures is vitally important for the safe and efficient operation of any complex system (p. 1113)."

Therefore, the use of operating procedures is very popular or even mandatory for large process control systems such as nuclear power plants (NPPs), commercial airplanes and railway systems (Degani et al., 1999; Hale, 1990; Sharit, 1998; Sherry and Feary, 1998; Vanderhaegen, 1999; Wieringa and Farkas, 1991). For example, in the case of NPPs operated in the Republic of Korea, all the tasks to be carried out under emergency conditions should be prescribed in emergency operating procedures (EOPs) (Lee et al., 2011). In addition, in the UK, the use of operating instructions is stipulated in Licence Condition 24 (HSE, 2011).

However, the improvement of an operational safety by providing operating procedures can be accomplished only if the following prerequisite is satisfied: "Human operators are able to properly obtain necessary information from operating procedures, which is indispensable for conducting the required tasks safely and effectively." That is, it is hard to anticipate the potential benefits of operating procedures (e.g., reducing work effort or the likelihood of human error), if task descriptions are so ambiguous or incomplete that human operators feel an undue difficulty in identifying "what should be done" and "how to do it" (Bhattacharya, 1997; Dien and Montmayeul, 1992; Frostenson, 1995; Hattermer-Apostel, 2001; Norman, 1981; Reer et al., 2004). This implies that the provision of necessary information contents can be largely affected by the level of task descriptions included in procedures. In addition, since many researchers have pointed out that the degree of ambiguity felt by human operators can be subjective (Adelson, 1984; Wagner et al., 1996; Zach, 1980), it is evident that proper task descriptions should be determined by the consideration of their operation experience and/or knowledge. In other words, each task should be described so that it contains sufficient information based on the consideration of "who is the user of this procedure?" Unfortunately, a practical framework that is helpful for determining the appropriate level of task descriptions along with the operation experience and knowledge level of human operators seems to be rare (McRobbie and Fiset, 2006; Wagner et al., 1996; Wieringa and Farkas, 1991). In this regard, one of the plausible starting points is to identify task description levels that can actually affect the difficulty of human operators in using procedures. That is, in order to develop a good procedure with the consideration of its user, it is necessary to know which levels of task descriptions should be avoided or encouraged.

For this reason, Park et al. developed systematic framework that can be helpful for identifying the level of task descriptions included in procedures (Park et al., 2010). To this end, the characteristics of task descriptions about emergency tasks included in the EOPs of NPPs were distinguished by the task analysis technique of TACOM (task complexity) measure that can be generally used to quantify the complexity of normative tasks to be done by human operators. After that, the relative difficulties of 12 kinds of task descriptions that frequently appeared in the EOPs were investigated based on the results of pair-wise comparisons conducted by 7 subject matter experts (SMEs) who have been working as training instructors in NPPs. As a result, decision chart that seems to be serviceable to distinguish three levels of task descriptions, such as detailed (DETAIL), intermediate (INTER) and problematic (PROB), was suggested.

However, it is still difficult to confirm the appropriateness of the decision chart because it just reflects the evaluation results of training instructors who were highly experienced in the operation of NPPs. In other words, since the degree of ambiguity felt by human operators can vary with respect to their knowledge and/or experience, it is inevitable to clarify the fact that the evaluation results of highly experienced human operators are consistent with those of less experienced human operators.

In order to ensure the appropriateness of the suggested decision chart, in this study, 7 kinds of hypothetical procedures were developed, in which the percentage of DETAIL, INTER and PROB level descriptions are different. Then in total 98 human operators who are working in domestic NPPs were asked to rate the subjective difficulty of each operating procedure using a 5-point Likert scale. Based on the ratings, the variation of subjective difficulty scores was analyzed with respect to the percentage of DETAIL, INTER and PROB level descriptions included in each hypothetical procedure. As a result, it was revealed that the subjective difficulty scores of human operators are inversely proportional to the amount of DETAIL level descriptions. In addition, it was consistently observed that the effect of PROB level descriptions on subjective difficulty scores is more significant than that of INTER level descriptions. Therefore, it is reasonable to say that the decision chart can be used to scrutinize the level of task descriptions included in procedures.

The organization of this paper is as follows. In Section 2, a framework by which the characteristics of task descriptions can be distinguished is explained with the decision chart suggested in the previous study. In Section 3, detailed explanations about how to additionally collect subjective difficulty scores for the 7 kinds of hypothetical procedures are described. In Section 4, a series of comparison results are provided in order to scrutinize relations between the level of task descriptions and the associated subjective difficulty scores. Finally, the conclusion of this study is drawn in Section 5 with discussions that emphasize some insights supporting the appropriateness of the suggested decision chart.

2. Characterizing the level of task descriptions

As already mentioned in the previous section, determining the proper level of task descriptions is one of the important factors for developing a good operating procedure. Regarding this, for example, Bovair and Kieras (1991) quoted the following sentences