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Development and validation of a heuristic model for evaluation of the team performance of operators in nuclear power plants

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ABSTRACT

The global concerns about safety in the digital technology of the main control room (MCR) are growing as domestic and foreign nuclear power plants are developed with computerized control facilities and human–system interfaces. In a narrow space, the digital technology contributes to a control room environment, which can facilitate the acquisition of all the information needed for operation. Thus, although an individual performance of the advanced MCR can be further improved; there is a limit in expecting an improvement in team performance. The team performance depends on organic coherence as a whole team rather than on the knowledge and skill of an individual operator. Moreover, a good team performance improves communication between and within teams in an efficient manner, and then it can be conducive to addressing unsafe conditions. Respecting this, it is important and necessary to develop methodological technology for the evaluation of operators' teamwork or collaboration, thus enhancing operational performance in nuclear power plant at the MCR.

The objectives of this research are twofold: to develop a systematic methodology for evaluation of the team performance of MCR operators in consideration of advanced MCR characteristics, and to validate that the methodology is adaptable to the advanced MCR of nuclear power plants. In order to achieve these two objectives, first, team performance factors were extracted through literature reviews and methodological study concerning team performance theories. Second, the team performance factors were identified and behavior markers were deducted based on the factors. Lastly, an estimation model for the evaluation of team performance was developed, and the model thereon was validated. The estimation model consists of an evaluation of task characteristics, identification of team performance factors, evaluation of team performance, calculation of team performance, and analysis of team performance. The detailed contents and validations of the model are also presented in this paper.

1. Background

As digital technology has been improved, an advanced MCR requires adaptation to new technology. The advanced digital technologies have created operating tasks for monitoring and controlling information, which can be efficient in a narrow space. The computer-based digital facilities are effective in improving individual performance. However, digital facilities may improve the task concentration of each person and yet induce static task environment, thus team performance might be reduced (Sebok, 2000; Hwang et al., 2007). The team is defined as two or more people who are appropriately interacting with each other, and the team is a dependent aggregate, which accomplishes a valuable common goal (Salas et al., 1992). The safe operating tasks of nuclear power plants can be guaranteed not by individual, but team efforts. Therefore, there is a characteristic that a team as a whole is able to exhibit higher performance through organizational combination than being dependent on individual knowledge or skills. A team can efficiently address risky situations through communication within and between teams as well. In that context, it is necessary that we must explore the improvement of team performance by measuring and analyzing the factors of operator teamwork and collaboration.

According to the DOE Handbook (DOE, 2009), about 80% of all events are attributed to human error. When the 80% human error is broken down further, it reveals that the majority of errors associated with events stem from latent organizational weaknesses, whereas about 30% are caused by the individual mistakes. Typically, human error has a leading above 60% contribution in almost all events (Romney, 2004). Specially, of the 101 human-related unplanned reactor trip events that occurred between 1986 and 2006,

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73% were associated with the human caused events in Korean nuclear power plants (Kim and Park, 2008).

When a nuclear power plant accident occurs, the degree of national severity is especially high given the suspension of power supply, the public damage and the huge loss of the plant itself. To reduce the human errors, efficient communication and improvement in team performances including team situational awareness are needed (Carvalho and Vidal, 2007; Sebok, 2000). Based on the situation of shift conventions and operator himself/herself, operators for the MCR are organized into an operating crew with a minimum change. Therefore, an operator can be designated as the team leader or a team member of the operating crew during normal times. Those changeable situations occur frequently in not only national but also overseas nuclear power plants, so that the problem of the team skills can be caused by those situations (Gaddy and Wachtel, 1992).

An important point to note is that the rate of team operation increased by 5% in 1980s and by 50% in the mid 1990s (Salas et al., 2004). As to an individual operation, he or she performs the tasks as a member of the team so that there is an assigned individual goal which each has to achieve and a team goal which a team has to attain. The team goal is also achieved through the performance of each individual goal. The goal performances of both individuals and the team, however, do not accord with each other; these can be differences depending on their team skills.

The nuclear power plants require a higher level of safety than other industries. Therefore, it is necessary that nuclear industries ensure safety. In case where it fails to do so, nations may suffer from reliability deterioration and public distrust. The MCR operators effectually perform the plant operational tasks as a team unit with monitoring plant information on various displays and controllers so that the nuclear power station can be safe. Therefore, the MCR operating tasks are composed of a series of cognitive processes including monitoring situations, detecting and perceiving data or information, interpreting and assessing situations, diagnosing symptoms, making decisions, and implementing responses, etc. (USNRC, 1989). Especially, in the case of the advanced MCR based on digital computers, the cognitive tasks are performed through input tools (e.g., mouse, keyboard, touch screen, etc.) and information displays (e.g., CRT, LCD, etc.). Individual performances can be improved in the advanced MCR using personal computers. However, it becomes possible for the team performance to be relatively degraded due to more personal tasks (Gaddy and Wachtel, 1992; Sebok, 2000). In this regard, objective tools to measure team skills and evaluation tools to evaluate the team performance need to be improved. Currently, measurement and assessment technology for team performance are insufficient compared to those for individual performance, however.

In this research, a methodology reflecting the characteristic (especially, the advanced MCR) of the nuclear power plant MCR operating tasks was developed. To objectively develop the method, first, the team performance factors were extracted through team performance theories and case studies. Second, a decision and evaluation behavior markers of team performance factors were drawn. Lastly, a behavior-based team performance estimation model was built. The estimation model for assessing team performance consists of evaluating task characteristics, identifying team performance factors, and evaluating/calculating/analyzing team performance. By applying the developed estimation model to a real case, the feasibility of the estimation model was verified.

2. Methodology

A method and procedure of this research for developing a team performance estimation model of MCR operators is schematized in Fig. 1.

2.1. Theoretical study

Not only in nuclear industry but also in aviation, railway, harbors, airport, chemistry, oil, and apparel industries, many accidents arising from human errors have appeared, and focus has been channeled into human error reduction activities (Campbell, 1971; Goldstein, 1980; Latham, 1988; Salas and Cannon-Bowers, 2001; Tannenbaum and Yukl, 1992; Wexley, 1984). In the past, the human error was approached focusing on the problems relating to individual activities and on the method to prevent such problems. Nowadays, such focus has been adjusted to incorporate systematic dimension, however.

In a systematic point about human error, many researchers had concerns about team errors as team tasks increase. The team performance can be determined in the outcome or achievement of a task and classified into individual and/or team performance according to the level of valuation. An important point of team performance is that cooperative aspects can be strengthened while accomplishing the common goal and synergistic effects can also be created. That is, the team performance, not just individual performance, carries more meaning than has been previously recognized. As to the definition of team performance, Argyris (1962) measured a performance as a rate of output per input. Georopoulus and Tannenbaum (1957) mentioned that the team performance is that an organization achieved the goal of an organization without unjust coercion about the waste of resources and organizational elements. Initial studies about the team performance focused on how the input element (e.g., team organization and tasks design) affected the output element (e.g., team performance and team satisfaction). The research about the interaction, in which it shows up between team organizations, was relatively insufficient when the team accomplished a task (Cohen and Bailey, 1997). However, the interaction, in which it shows up between team organizations, that is, the research about the team process, has actively been accomplished recently.

The team performance research was approached based on a theoretical frame of the 'input → process → output' (see Fig. 2). It is concerned with the process as a member or team and with the characteristics and mechanism in which it mediates the team characteristics of an organization (Marks et al., 2001). The team process as an intermediary means a communication among team members, leadership, and so forth. It refers to a team skill or a teamwork element thereon. The team skill relates to a function of the team with the element necessary in the process of achieving the team performance.

The significant aspects of the team process were emphasized by many researchers. However, a definition regarding the team process concept was not clearly presented. Several team process concepts in which are presented from the existing research on team are given in Table 1.

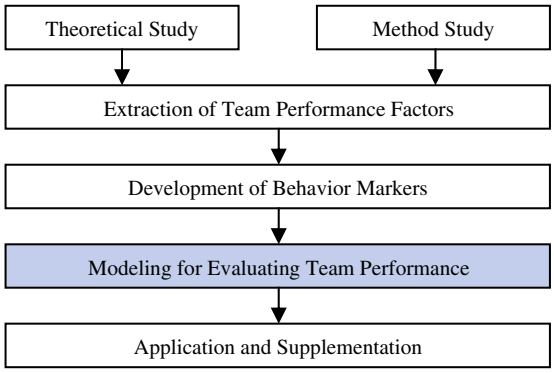

Fig. 1. Method and procedure.