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Original Article

A Quantitative Team Situation Awareness Measurement Method Considering Technical and Nontechnical Skills of Teams

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Human capabilities, such as technical/nontechnical skills, have begun to be recognized as crucial factors for nuclear safety. One of the most common ways to improve human capabilities in general is training. The nuclear industry has constantly developed and used training as a tool to increase plant efficiency and safety. An integrated training framework was suggested for one of those efforts, especially during simulation training sessions of nuclear power plant operation teams. The developed training evaluation methods are based on measuring the levels of situation awareness of teams in terms of the level of shared confidence and consensus as well as the accuracy of team situation awareness. Verification of the developed methods was conducted by analyzing the training data of real nuclear power plant operation teams. The teams that achieved higher level of shared confidence showed better performance in solving problem situations when coupled with high consensus index values. The accuracy of nuclear power plant operation teams' situation awareness was approximately the same or showed a similar trend as that of senior reactor operators' situation awareness calculated by a situation awareness accuracy index (SAAI). Teams that had higher SAAI values performed better and faster than those that had lower SAAI values.

1. Introduction

Individuals have their own strengths and weaknesses. Those strengths become more powerful when strengths are assembled; the so-called "synergy effect". Sometimes, one person's strengths complement another's weaknesses. Team members can give warnings to each other and correct other members' abnormal behavior and opinions by offering other points of view so that human error can be prevented or, at least, serious consequences caused by human behavior can be mitigated. In addition to these general reasons, running nuclear power plant (NPP) systems is beyond a single person's ability. Thus,

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NPPs are basically designed to be run by people with various specialties and abilities working together. Normally, NPP operation skills are composed of technical and nontechnical skills. Technical skills deal with areas of science related to plant operation [1]; nontechnical skills are areas of sociology related to information exchanges among plant operators [2]. In our previous research, evaluation methods for both skills have been proposed; however, the proposed methods have two critical disadvantages in any sort of direct application in team evaluation. First, the proposed technical skills evaluation method was originally developed for the evaluation of individuals; separately evaluated results for operators should be put through a comparison analysis. Another problem is that technical skills and nontechnical skills should be collectively analyzed, because they are not mutually exclusive. In this paper, an integrated skill training model and a team performance evaluation method that considers the interdependency of technical and nontechnical skills are suggested.

2. Development of an integrated training model

No adequate training model for NPP operation teams has been developed. Fortunately, the design of technical skills training, such as technical lectures and simulation-based training to deal with abnormal situations, can be based on a systematic approach to training (SAT). Likewise, the design of nontechnical skills training requires a framework. Furthermore, the integrated skill training model will help improve the operation skills of personnel.

2.1. SAT

SAT is defined as a "logical progression from the identification of competences to the development and implementation of training towards achieving these competences" [3]. SAT-based training is recommended by the International Atomic Energy Agency (IAEA)a for the training of NPP personnel. It is also a requirement/standard in most countries in which NPPs operate. This is codified in the safety guide as follows: "a systematic approach to training should be used for the training of plant personnel." [4].

The purpose of training is to learn something, so after training, evaluation must be put into place to check how much trainees have learned and to modify training to yield better results from the next training. One cycle of such steps is called a learning unit (LU). The LU is a formulation that facilitates change, a change that will result in the trainee being able to do something he/she could not do before going through the LU. In other words, the LU facilitates a change in behavior. There are four principal stages in a typical LU model as shown in Fig. 1 [5]. The steps are summarized as follows. (1) A training objective must be set before training. (2) Trainers need to know the level of trainees. This step requires the use of an evaluation method. (3) Trainers conduct training. (4) Performance should be assessed to check the effect of training.

A typical LU of SAT is shown in Fig. 2. Actually, the IAEA recommends that training courses and seminars on management and supervisory skills, coaching and mentoring, self-

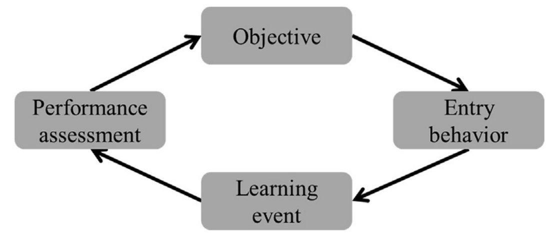

Fig. 1 – A simple model of a learning unit.

assessment techniques, root cause analysis, team training, and communication be developed based on SAT. Most of the items mentioned here are related to nontechnical skills. Unfortunately, nontechnical skills training has been overlooked in Korea and thus, no well-developed nontechnical skills training programs based on SAT, nor evaluation methods, are currently applied to further improve the operation skills of NPP operation teams. Therefore, SAT was applied to the development of simulation training and technical and nontechnical skills evaluation processes in this research.

2.2. Integration of technical and nontechnical skill training

Training systems in the nuclear industry are somewhat biased toward enhancing technical skills. For example, nontechnical skill training has been given in one-off seminars in Korea. Most of the training sessions related to the operation of NPPs utilized virtual reality running on a simulator. Thus, for efficiency's sake, the evaluation of technical and nontechnical skills together in one session of simulation training is necessary. A new model of skill training and evaluation processes is required to properly integrate and evaluate these two disciplines; such a model should be able to consider the interdependency of these skills. Interdisciplinary training is "a process of answering a question, solving a problem, or addressing a

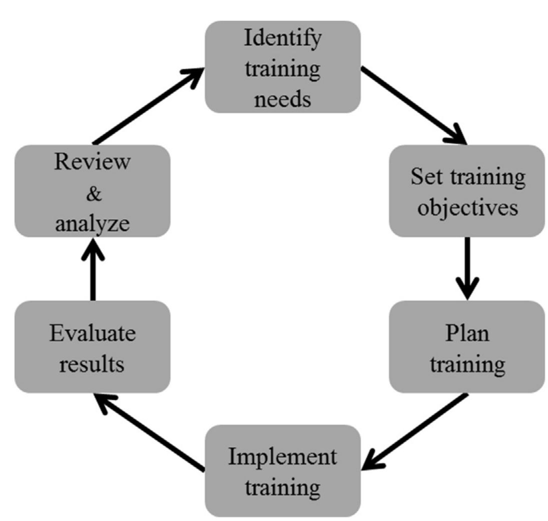

Fig. 2 – A typical LU of SAT. LU, learning unit; SAT, systematic approach to training.

topic that is too broad or complex to be dealt with adequately by a single discipline or profession," and "draws on disciplinary perspectives and integrates their insights through the construction of a more comprehensive perspective" [6]. The most important focus of interdisciplinary training today is on real world problems. Interdisciplinary training, particularly in the sciences and in some areas of the social sciences, tends to be *ad hoc*. As Newell [7] expresses it, interdisciplinary learning takes disciplines out of the academy and into the real world.

As can be seen in various works in the literature, the integrated model of skill training has been suggested for certain situations, as shown in Fig. 3. New evaluation methods are also needed for two types of skills when considering their interdependency as explained in the next section.

3. Development of quantitative evaluation methods

First of all, factors are chosen for each skill. Endsley's [8] situation model and the operator's cognitive process [9], as shown in Fig. 4, identify that an operator's cognitive activities between the acquisition of information and operation actions are comprised of situation awareness (SA) and decision making. Considering that these models can be broadened to include a team aspect, team SA and team decision making are prime factors that affect team performance. Thus, simulation training was conducted based on the developed integrated skill training model, and team performance was evaluated by measuring team SA and team decision making.

3.1. *Team SA*

It has been argued that, at a simple level, team SA comprises three separate but related components: individual team member SA, the SA of other team members (task-work SA), and the SA of the overall team (teamwork SA). The team SA was selected as an indirect measure of the technical and nontechnical skills of operation teams, based on a literature survey that included several relevant works of previous research. In this light, team SA can be defined as the sum of the technical and nontechnical skills of each member of the team, as shown in Fig. 5 [10].

Team SA has received less attention than individual SA. The elaboration of SA in complex, collaborative environments thus remains a challenge for the human factors research community, both in relation to the development of theoretical perspectives and of valid measures, and to the development of guidelines for systems, training, and procedure design [10]. The NPP operation environment is known as "C4i: command, control, communication, computers and intelligence". C4i is the management infrastructure for defense and war or of any other large or complex and dynamic resource systems [11]. C4i systems comprise both human and technological agents and are designed to gather information and facilitate the accurate communication of this information between multiple agents dispersed across multiple locations [12]. SA measurement techniques for operators in such environments have to be able to satisfy the following requirements: (1) the technique should be capable of measuring SA simultaneously at different geographical locations. (e.g., between main control room (MCR) and the field); (2) the technique should be capable of measuring both individual and team or shared SA; and (3) the technique should be capable of measuring SA in real time.

Unfortunately, the techniques that are currently in use have some limits in terms of satisfying all three of these requirements. Again, Bayesian inference has been chosen as the best way to accomplish those goals. Previously, quantitative values as determined through Bayesian inference have been defined according to the level of confidence of an operator in a specific situation [13]. The level of confidence of each operator for the expected situation is known to vary with the amount of information that each operator has received. Thus, team SA as used in this study is defined as the level of shared confidence. In Fig. 6, it can be seen that if the level of confidence of a senior reactor operator (SRO) for situation A is assumed to be 0.9, and

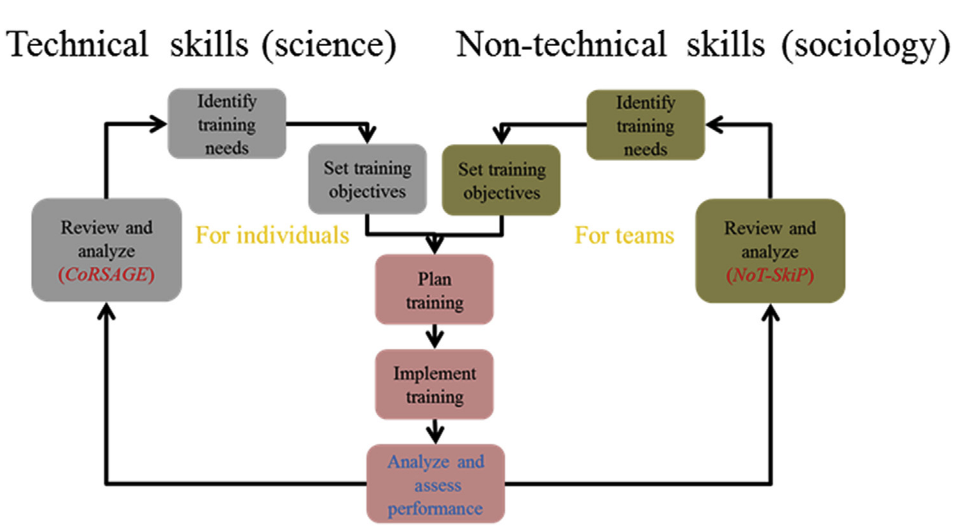

Fig. 3 – An integrated model of skill training for NPP operation teams. CoRSAGE, computational representation of situation awareness with graphical expressions; NPP, nuclear power plant.

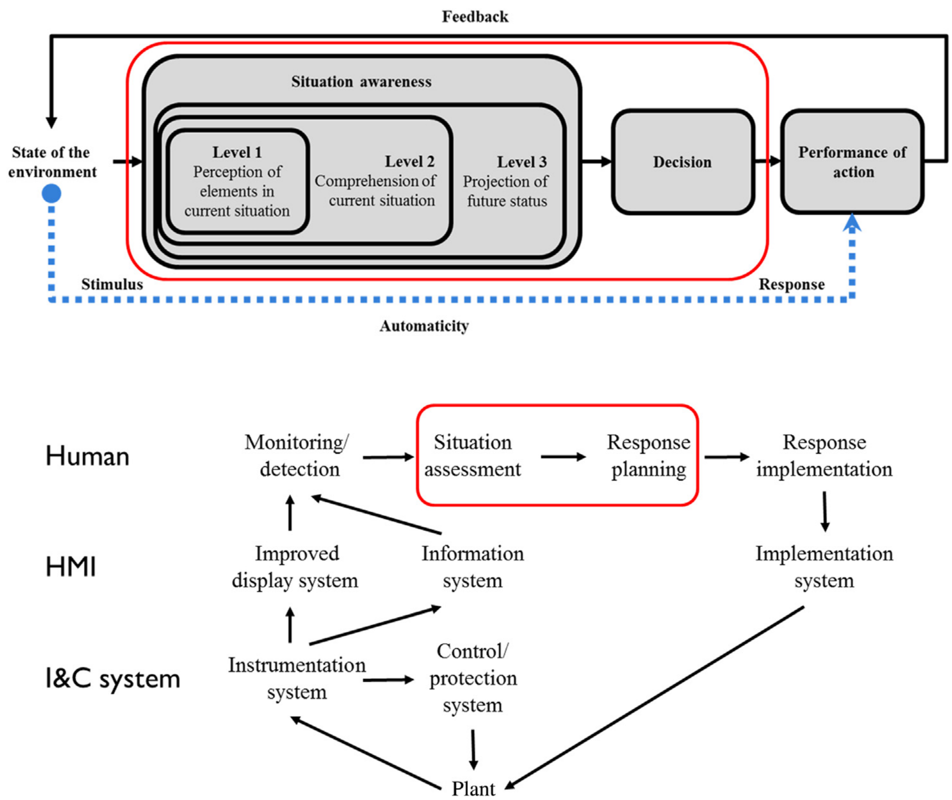

Fig. 4 – Endsley's model of situation awareness and NPP operation process with the indirect support system. HMI, human machine interface; I&C, instrumentation and control; NPP, nuclear power plant.

if that level is 0.7 for the reactor operator (RO) and 0.1 for the electric operator (EO), the shared portion of the level of confidence for all members is 0.1. Likewise, the shared portion of the level of confidence for the two members is 0.6 (0.7–0.1); all of this can be generalized as Eq. (1). The core concept of this method is the ability to measure the shared amount of SA; therefore, the level of confidence of 0.2 (0.9–0.7) as perceived by one operator is excluded.

$$Level\ of\ shared\ confidence(LSC) = a_1 + \sum_{i=2}^{n-1}(a_i - a_{i-1}) \times \frac{n-i+1}{n} \quad (1)$$

where, $0 \le a_1 \le a_2 \le a_3,\ldots, \le a_n \le 1$.

LSC simply means that the sum of cross sections of each member's SA weighted by numbers of team members who share confidence. Thus, the portion of SA that someone owns alone does not count. Examples of the level of confidence are shown in Table 1.

3.2. *Team decision making*

Nontechnical skills were measured based on four important factors by the measure called Non-Technical Skills Preparedness (NoT-SkiP) [14]. However, measuring nontechnical skills using only a few factors does not seem to be enough, because nontechnical skills, if one takes the time to enumerate such skills regardless of their relative importance, can be almost

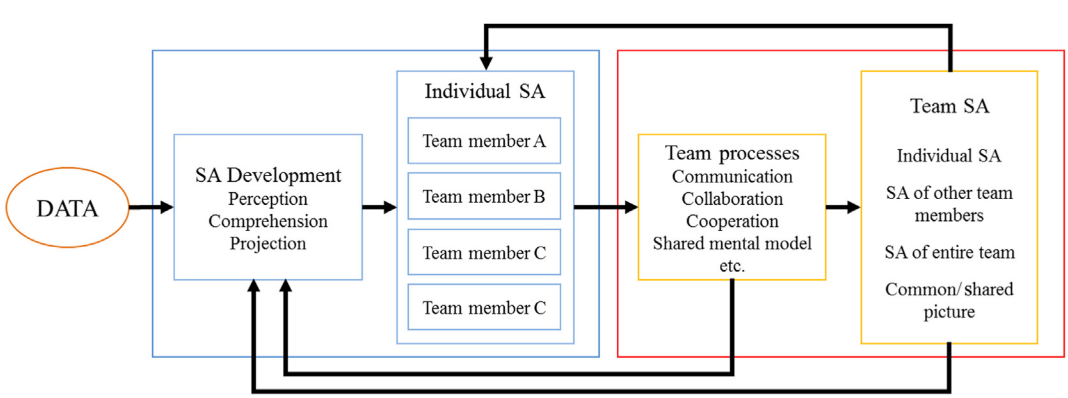

Fig. 5 – A process of team SA. SA, situation awareness.

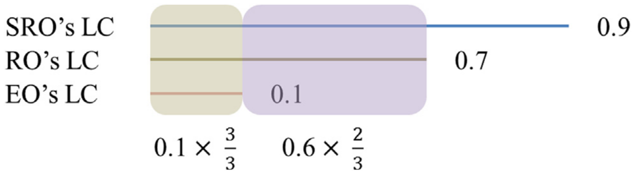

Fig. 6 – An example of LSC. EO, electric operator; LSC, level of shared confidence; RO, reactor operator; SRO, senior reactor operator.

anything. Contrary to the idea of team SA, team decision making, which is the last step of the human cognitive process, can be the final destination of a cognitive activity when all sorts of nontechnical skills are exerted based on the technical skills of the team. Therefore, nontechnical skills, when considering the technical skills of teams, could be measured by measuring the level of team decision making quantitatively. Decision making can be regarded as a cognitive process that results in the selection of a course of action among several alternative scenarios. Every decision making process produces a final choice [15]. The output can be an action or an opinion of choice [16]. Payne et al [17] also defined decision making as an individual's use of multiple decision strategies in different situations, including various simplifying methods or choice heuristics; it is an adaptive response of a limited capacity information processor to the demands of complex decision making.

Table 1 – Examples of LSCs and CIs.

Operators	*LConf*	*LSC*	*CI*
CASE 1			
SRO	0.9000	0.3500	0.3889
RO	0.6000		
EO	0.1000		
TO	0.1000		
CASE 2			
Operators	*LConf*	*LSC*	*CI*
SRO	0.7000	0.3500	0.5000
RO	0.6000		
EO	0.1000		
TO	0.1000		
CASE 3			
Operators	*LConf*	*LSC*	*CI*
SRO	0.9000	0.4000	0.4444
RO	0.7000		
EO	0.1000		
TO	0.1000		
CASE 4			
Operators	*LConf*	*LSC*	*CI*
SRO	0.9000	0.3750	0.4167
RO	0.7000		
EO	0.1000		
TO	0.0000		
CASE 5			
Operators	*LConf*	*LSC*	*CI*
SRO	0.9000	0.0000	0.0000
RO	0.0000		
EO	0.0000		
TO	0.0000		
CASE 6			
Operators	*LConf*	*LSC*	*CI*
SRO	0.5000	0.5000	1.0000
RO	0.5000		
EO	0.5000		
TO	0.5000		

CI, consensus index; EO, electric operator; LConf, level of confidence; LSC, level of shared confidence; RO, reactor operator; SRO, senior reactor operator; TO, turbine operator.

The term "team decision making" is not pervasively used. Instead, consensus decision making seems to be a more popular term. Consensus decision making is a group decision making process that seeks the consent of all participants. Consensus may be defined professionally as an acceptable resolution, one that can be supported, even if it is not the "favorite choice" of each individual. Consensus is defined in Merriam–Webster's dictionary as general agreement and as group solidarity of belief or sentiment. It is used to describe both a decision and the process of reaching a decision. Consensus decision making is thus concerned with the process of deliberating and finalizing a decision [18].

Decision problems often involve conflicts between values, because no one option best meets all of the objectives. Some of the decision strategies used by people can be thought of as conflict confronting, and others can be thought of as conflict avoiding [19]. This statement mainly represents a personal perspective. When this statement is broadened to a team scale, conflict between members will become the main problem.

According to the literature, the idea of a consensus index has been proposed in Eq. (2).

$$Consensus\ index(CI) = \frac{LSC}{\max(A)} \tag{2}$$

where, $A = \{b_1, b_2, b_3, \ldots, b_n\}$.

The notation "b_i" represents a level of confidence that each team member has. "max(A)" here means the highest level of confidence for a random situation X that the most informed operator holds. If max(A) is wholly shared by team members and they all have max(A), then, this means that all members fully agree that the confronted situation is X. CI implies the equality level of SA. If every member in the team has the same level of SA, then CI of the team is 1. If dominant members in SA appear, CI gets lower. Examples of CI are also shown in Table 1. An abbreviation "TO" in Table 1 means a turbine operator.

3.3. *Accuracy of situation awareness*

Accuracy is the prime concern when measuring SA. No matter how confident an operator is that the confronted situation is X, if the real situation is Y, the operator is using inappropriate technical skills. An accuracy measure that can reflect the whole set of steps of SA was therefore required because the process was an important factor in the study. First, accuracy deviation using the root-mean-square deviation (RMSD) method was proposed, as shown in Eq. (3). Where, $LConf_{ref}$ is reference level of confidence and $LConf_o$ is operator's level of confidence.

$$Accuracy\ deviation(AD) = \sqrt{\frac{\sum_{i=1}^{n}\left(LConf_{ref,i} - LConf_{o,i}\right)^2}{n}} \quad (3)$$

The SA accuracy index can be calculated using *AD* as shown in Eq. (4).

$$Situation\ Awareness\ Accuracy\ Index(SAAI) = 1 - \frac{AD}{\sqrt{\frac{\sum_{i=1}^{n}\left(LConf_{ref,\,i}\right)^2}{n}}} \quad (4)$$

Strictly speaking, SAAI was developed to estimate the SA of individuals under training or real conditions by comparing actual individuals' SA with reference SA. Reference SA is intended SA in training conditions or presumed SA under the situation that we best understand. Team SA can be partially deduced by summing SAAIs of each member in the team. $LConf_{ref}$ of a simple example shown in Table 2 is taken from the first 20 minutes of the reference LOCA training scenario. Designed plant states that teams must be aware of coolant leaking, operation limit abnormality, leak inside the containment, and incomplete LOCA isolation in sequence. Operators should notice these plant states by the timely activated alarms and indicators as designed. When the team exactly follows the process that the reference indicates, then the SAAI is 1. It means that the operator understands and exactly knows exactly what to do in such a situation. On the contrary, if the team does not at all follow the process as the reference indicates, then the SAAI is 0. An Example of SAAIs of real operation Teams 1 and 3 shown in Table 3 and detailed findings are depicted in the following results section.

4. Case study

4.1. *Data collection of an LOCA condition*

To compare these results with the results of NoT-SkiP, loss of coolant accident (LOCA) cases for the APR-1400 type reactor, which was a new system to all participants, were considered for verification of the integrated evaluation method. LOCA emergency operation training of real plant operators in the training center of the reference plant was recorded by Korea Hydro & Nuclear Power Co. Ltd. Nine operation teams participated in the training, and each team performed one scenario. Training time was limited to ~ 50 minutes, to allow for a fair comparison. An introduction part which was irrelevant to the process of the main scenario was removed from the data.

Table 2 – A virtual example of SAAIs.

Situations to identify	$LConf_{ref}$	$LConf_{teamA}$
Coolant leaking	0.9987	0.9987
Operation limit abnormality	0.5000	0.5000
Leak inside CTMT	0.9971	0.9971
Incomplete LOCA iso.	0.9995	0.9995
SAAI	1.0000	
Tasks to identify	$LConf_{ref}$	$LConf_{teamB}$
Coolant leaking	0.9987	0.0000
Operation limit abnormality	0.5000	0.0000
Leak inside CTMT	0.9971	0.0000
Incomplete LOCA iso.	0.9995	0.0000
SAAI	0.0000	

CTMT, containment; iso., isolation; $LConf_{ref}$, reference level of confidence; $LConf_{teamA}$, team A level of confidence; LOCA, loss of coolant accident; SAAI, situation awareness accuracy index.

Table 3 – An example of SAAIs for Teams 2 and 9.

Situations to identify	$LConf_{ref}$	$LConf_{team2}$
Coolant leaking	0.9987	0.3333
Operation limit abnormality	0.5000	0.0000
Leak inside CTMT	0.9971	0.9975
Incomplete LOCA iso.	0.9995	0.0000
SAAI	0.2775	
Tasks to identify	$LConf_{ref}$	$LConf_{team9}$
Coolant leaking	0.9987	0.9987
Operation limit abnormality	0.5000	0.0000
Leak inside CTMT	0.9971	0.9960
Incomplete LOCA iso.	0.9995	0.9981
SAAI	0.7222	

CTMT, containment; iso., isolation; $LConf_{ref}$, reference level of confidence; $LConf$, level of confidence; LOCA, loss of coolant accident; SAAI, situation awareness accuracy index.

5. Results and discussion

The LSCs and CIs for the nine teams are shown in Table 4. LSC and CI values of Team 1 were 0 because Team 1 considered the situation as a mixed event of steam generator tube rupture and loss of feed water accident rather than LOCA. However, Team 1 scored 28 for the operator performance assessment system (OPAS) developed by the Organization for Economic Cooperation and Development (OECD) Halden Reactor Project, because some functions indicated and operated by Team 1 were also used for a LOCA scenario. Judging by the results, technical skills affect performance more than nontechnical skills do, so teams with higher LSC scores showed better performance. If a team has low technical skills, the team is likely to have wrong values for SA or low values for LSC. There is the possibility that a team with high CI and low LSC scores may make an incorrect decision easily because CI has been used to measure nontechnical skills. Teams 2–4 that failed to achieve a given mission had similar OPAS scores compared with that of Team 7, which succeeded to resolve given tasks. Failed teams had fairly good CI values. Therefore the only reason that could explain the difference between failure and success was LSC scores. As mentioned, when the LSC score is high, a high CI score accelerates to spread correct SA among members. On the contrary, the possible explanation of team performance with a high CI, LSC scores is that teams are either very active in sharing their knowledge to figure out what is happening, and yet do not know what it is and try hard to solve problems, but they misunderstand the situation, resulting in low LSC scores. Team 7 had a better LSC score and a little higher LConf value of

Table 4 – Examples of LSC and CI for Teams 1–9.

TEAM 1 (failed, OPAS 28)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.0000	0.0000	n/a
RO	0.0000		
EO	0.0000		
TO	0.0000		
TEAM 2 (failed, OPAS 46)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.6213	0.2647	0.4260
RO	0.4443		
EO	0.0000		
TO	0.1701		
TEAM 3 (failed, OPAS 42)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.4996	0.1874	0.3750
RO	0.3332		
EO	0.0000		
TO	0.0830		
TEAM 4 (failed, OPAS 47)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.7970	0.2593	0.3253
RO	0.4335		
EO	0.0000		
TO	0.1701		
TEAM 5 (failed, OPAS 51)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.7970	0.2993	0.3755
RO	0.5180		
EO	0.0408		
TO	0.1203		
TEAM 6 (failed, OPAS 40)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.7166	0.1265	0.1765
RO	0.2114		
EO	0.0000		
TO	0.0830		
TEAM 7 (succeeded, OPAS 45)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.8880	0.3180	0.3581
RO	0.5377		
EO	0.0408		
TO	0.1556		
TEAM 8 (succeeded, OPAS 55)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.5660	0.2797	0.4942
RO	0.4993		
EO	0.0000		
TO	0.1203		

Table 4 – (*continued*)

TEAM 1 (failed, OPAS 28)			
Operators	*LConf*	*LSC*	*CI*
TEAM 9 (succeeded, OPAS 63)			
Operators	*LConf*	*LSC*	*CI*
SRO	0.8880	0.4292	0.4834
RO	0.7530		
EO	0.0408		
TO	0.1701		

CI, consensus index; EO, electric operator; LSC, level of shared confidence; OPAS, operator performance assessment system; RO, reactor operator; SRO, senior reactor operator; TO, turbine operator.

the SRO than those of three teams. The evaluation result suggest that the SRO of Team 7 had more knowledge in a given situation, actively shared information among members more than the other three teams, and led the team to successfully complete the mission. After the postexperimental investigation, we found out that the SRO for Team 8 had previous knowledge and experience through similar training courses. The SRO collected the least relevant information from expected places and sought extra information from elsewhere, such as operators' outside or general knowledge. Consequently, the calculated LSC value was low. The SRO exchanged most information with the RO in the LOCA scenario; thus, nontechnical skills between them made up the majority of the nontechnical skills of the team. An interesting point is that the CI value of Team 8 was very high; this means that the SRO and the RO were very active in exchanging information and making decisions. The results for individual operators' SA and nontechnical skills can be evaluated by using Computational Representation of Situation Awareness with Graphical Expressions (CoRSAGE) and NoT-SkiP. Team 1 seemed to have very low knowledge. Team 5 could have succeeded a given mission if they had a little more time. They had fairly good scores in OPAS, LSC, and CI, but they were very slow to complete the substeps. Unfortunately, this matter of "time limitation" does not appear in any of the developed measures. Other performance measures, such as completion time, can be required to get a good evaluation result. Team 6 failed in the given mission; it even had a high OPAS score because LSC and CI were too low to solve the problems. Team 8 had a high OPAS score because the SRO acquired essential information selectively. However, a low LCS score tells us that information on a certain team is biased and, sometimes, this kind of blocked information current may cause critical operation failures. The LSC and CI values for Team 9 were high, as was the OPAS score. Apparently, Team 9 performed the best among the nine teams. SAAI can be used for both individuals and teams. One restriction when using SAAI for the team SA measure is that the structure of teams to make decision is horizontal, and all members have the same portions of power to participate in the decision making process. If the team has a hierarchical decision making structure, using adjustment features, such as the weighting factor, are recommended to balance the portion of impact among members that might lead evaluators to a misinterpretation of team SA. A practical problem, of course, is that many cases for each team are required to draw representatively exact weights. There were two assumptions to explain SAAI with real training conditions. The team structure of Korean NPPs is unique in that the order in rank is rather firm, and the decisions flow from top to bottom. Thus most of the decisions were coming out of the SRO. This study also assumed that information regarding all situations in the MCR converges to the SRO in a timely manner. With these assumptions, an SRO's SA fully represented team SA in the example case of Table 3. Operators in Team 9 gave the exact information that a training designer expected for the first part of the scenario. However, operators in Team 2 missed delivering some pieces of information to the SRO, who was not as confident as the SRO of Team 9 that there was a leak point in the plant. SROs in both teams were not able to recognize that the plant operation limit condition was not normal, because none of the members in either team succeeded in delivering suitable information to their SROs. When LConfs are defined, SAAI is calculated by deviations of SRO's confidence for each state that the training designer designates as being important for trainees to deal with confronting situations that can be acquired by following reference situations. The teams that had SROs scored relatively high SAAI. For example, Team 5 failed on some occasions because team structures for making decisions were more horizontal than we assumed, and thus precise weighting factors were required to draw a correct evaluation result using SAAI. In this case, *SAAI* is recommended for use with other measures such as CI or OPAS. However, SAAI showed its capability in supporting the team performance evaluation process and that a good understanding of situations helps solve problems.

6. Discussion

An NPP is basically designed to be run by people with various specialties and abilities working together. Operators have to be trained to maintain their operation capabilities above a certain level by law in many countries. Training is defined as “the systematic development of the knowledge, skills and abilities (KSAs) required by an individual to perform adequately a given task or job” [20]. This implies that the role of training is to achieve the right mix of the KSAs of trainees and to help jobholders to perform tasks successfully. Therefore, the term “performance” for teams is interwoven with training. To achieve performance improvement, especially in the nuclear industry, training must lead operators to an enhancement of professional knowledge and skills both at individual and team levels. It should equip operators to respond appropriately to emerging challenges, such as reactor trips or perturbations of plant parameters, as well as to appropriate changes in attitude.

As has already been mentioned, NPP operation skills are composed of technical and nontechnical skills, and evaluation methods for each skill have been developed. In this paper, an integrated skill training model and training evaluation methods that can consider the interdependency of technical and nontechnical skills have been proposed to help improve performance of NPP operation teams. For integrated training evaluation, team SA and team decision making were selected as measurands. There have been several attempts to measure team SA, so it is worthwhile to develop valid measures of team SA for many potential applications. The developed SA measurement technique satisfies the requirements for a C4i environment: (1) measuring SA simultaneously at different geographical locations; (2) measuring both individual and team or shared SA; and (3) measuring SA in real time. Measuring team SA is attempted by considering nontechnical skills, and a quantitative approach enables training evaluators to include as many trainees as they could consider regardless of trainees' geolocation. Also, the development of an automated calculation tool enabled real time SA measurement. Accuracy is the prime concern when measuring SA to a good level of confidence. Thus, an accuracy measure that can reflect the whole set of steps of SA has been proposed that defines *AD* based on the root-mean-square deviation method. Decision making problems often involve conflicts between values, because no one option best meets all of our objectives. The term “team decision making” is not pervasively used. Instead, consensus decision making seems to be the more popular term. Consensus decision making is a group decision making process that seeks the consent of all participants; thus, the idea of CI has been proposed for teams. The values from each method can give trainers profound insights into any considerations of technical and nontechnical skills together. These values can also be used in debriefing sessions that are normally held for analysis of training. One strong point in the use of quantitative methods is that measures can approximately define relatively insufficient skills with clear distinction, so that rapid remediation can be given to trainees. The proposed methods still have shortcomings for a direct application to team performance evaluation during training. One is that the proposed methods still require a collective analysis of technical and nontechnical skills for further detailed evaluation results. CoRSAGE, the technical skills evaluation method, was originally developed for the evaluation of individuals and thus, separately evaluated results for operators should be subject to a comparison analysis. There is still a need for more data sets to statistically validate the methods. Although, the results so far shows strong advantages in addressing team behaviors that currently used methods such as OPAS cannot exactly express in simulator based team training. *LSC* and *CI* can instantly represent team characteristics at any time during the training session, and we hope that these features will enhance training efficiency.

Conflicts of interest

All authors have no conflicts of interest to declare.

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