Estimation method to determine the optimized automation level considering loss of situation awareness of human operators in nuclear power plants (NPPs)

LEE Seung-min[1], **KIM Jong-hyun**[2], **and SEONG Poong-hyun**[3]

1. Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 305-701, Daejeon, Republic of Korea (jewellee@kaist.ac.kr)
2. KEPCO International Nuclear Graduate School, 1456-1, Shinam-ri, Seosaeng-myeon, Ulju-gun, Ulsan, Republic of Korea (jonghyun.kim@kings.ac.kr)
3. Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 305-701, Daejeon, Republic of Korea (phseong@kaist.ac.kr)

Abstract: Automation has been introduced to reduce human error and to enhance performance in various industrial fields, including the nuclear industry. However, the excessive introduction of automation can generate new roles for human operators and changes activities in unexpected ways. Thus, to determine the appropriate introduction of automation has been an important issue. In this paper, the level of ostracism (LOO), which is the degree of difficulty in obtaining information from an automated system, is defined by analyzing the negative aspects of introducing automation. In addition, an analysis method to select an appropriate automation level considering both positive and negative effects at the same time is proposed.

Keyword: automation; level of automation (LOA); out-of-the-loop; situation awareness

1 Introduction

Automation refers to the use of a device or a system to perform a function previously performed by a human operator. It is introduced to reduce the human errors and to enhance the performance in various industrial fields, including the nuclear industry. However, these positive effects are not always achieved in complex systems such as nuclear power plants (NPPs). An excessive introduction of automation can generate new roles for human operators and change activities in unexpected ways. As more automation systems are accepted, the ability of human operators to detect automation failures and resume manual control is diminished. This disadvantage of automation is called the Out-of-the-Loop (OOTL) problem [1,2,3]. We should consider the positive and negative effects of automation at the same time to determine the appropriate level of the introduction of automation.

Many researchers have studied how to avoid the OOTL problem, and in some of those studies, researchers defined the level of automation (LOA), the degree to which an activity is automated, ranging from manual to fully automated [4]. Some LOA studies attempted to derive an appropriate level of automation systems to be applied in industrial fields. Parasuraman and Sheridan offered an acceptance level of automation for an air traffic control (ATC) system in which ground-based controllers direct aircraft and control air space [5]. In the nuclear fields, NUREG-0711 supports experts in their efforts to select the LOA according to the required function for conducting a task by providing a guideline for an analysis suitable for conducting the tasks among human operators and automation systems with respect to the performance demands, operating experiences, and economical aspects, among other factors.

However, how to optimize the proportion of automation for the best human performance remains unclear because most existing methods are dependent on the experts' opinions without a systematic process to analyze the positive and negative effects of automation in either case.

Thus, in this paper, we provide an opportunity to consider the positive and negative effects of automation at the same time to determine the appropriate introduction of automation. Based on the

Received date: December 31, 2014
(Revised date: March 2, 2015)

analyses of the causes of the OOTL problem, we define the level of ostracism (LOO), which is the degree of difficulty in obtaining information from an automated system. An optimization method for determining the automation level is proposed by suggesting the relationships between the LOA and the suggested LOO. The optimized combination of the automation level can be derived by selecting an appropriate combination of LOO and LOA for each task in as multi-task job. The suggested optimization method will be useful to support the determination of the introducing automation with the best performance in an actual plant situation.

2 Analysis of the negative effects of automation

2.1 Detection failure

Many OOTL-related studies have insisted that OOTL-induced performance problems can be attributed to a number of underlying factors, including: vigilance decrements, complacency, and the loss of operators' situation awareness [6]. Through these negative factors, the mechanism of the OOTL and the representative causes of the OOTL problem were analyzed.

It is clear that automation reduces the number of tasks and the required cognitive load as positive effects of automation. However, it can be differently interpreted that automation provides less information to operators compared to manual operation. In the nuclear industry, the automation system's interception of information takes away the chance of human operators to participate in the operation of the NPP. Thus, the excessive introduction of automation can result in immoderate dependence on automation, which can generate failures to maintain operators' attention in detecting and monitoring situations.

Automation systems such as computerized operator support systems (COSS) replace human operators' work and transform manual actions and decision making tasks into simple monitoring work. The decreased workload makes it difficult for human operators to maintain their attention, and the signs of abnormal situations in NPPs may not be detected as a result. Maintaining attention and alertness over a prolonged period of time is called vigilance [7], and the deterioration of remaining vigilant for critical signals over time, as indicated by a decline in the rate of the correct detection of signals, is called a vigilance decrement [8]. The operator's ability to detect changes depends on whether humans are actively involved in task control versus whether they are simply monitoring or supervising the process [9,10]. Thus, it is expected that as more automation is introduced, a more severe vigilance decrement will arise.

A vigilance decrement can occur and can cause detection failure regardless of whether or not the automation fails. Although human operators may not recognize the plant situation due to the vigilance decrement, this dangerous situation does not arise when automation does not fail. However, if automation fails, detection failure by human operators can be directly linked to an accident, as it is difficult to determine an opportunity to rectify the system without a sufficient understanding of the situation that is occurring. Thus, it is necessary to analyze how the vigilance decrement affects human operators when they are responsible for detection failures.

2.2 Interrupting factors for observing information

To prevent detection failures, how human operators are affected by automation and how much they can be affected by automation should be analyzed.

Many issues associated with human interaction with automated systems have been attributed to poor situation awareness [11]. SA is the ability to identify, process, and comprehend the critical elements of information to determine what is happening. Simply, it involves evaluating current conditions and knowing what is going on in one's immediate environment. Maintaining SA can be difficult when the operator is largely removed from directly performing an activity [6,12]. Lee stated that the OOTL problem is a loss of SA pertaining to the behavior of automation and the states of the system being controlled in part due to a failure to monitor the automation [13]. O'Hara et al. insisted that human operators' SA decreases as the level of automation increases [14]. The loss of SA is primarily referred to as the most significant reason for the OOTL problem. The causes of the OOTL problem are described in Fig. 1.

As shown in Fig. 1, some information cannot be given to human operators because the automation does not allow human operators to receive it. Automation substitutes for the human operators' work and delivers less information to human operators, information that they must know. In other words, the automation process intercepts the information, and human operators cannot get a sufficient amount of it, which they may need to know. This information interception process makes it difficult for human operators to sustain their attention to obtain the information. If human operators have a vigilance decrement, they miss the information provided by the automation. Thus, human operators may miss information that they monitor, despite the fact that the automation clearly provides it. As more information that human operators should have is missing, regardless of the reasons, the ability to understand the current situation decreases. This is the loss of SA, which finally generates a detection failure and the OOTL performance problem. Thus, to analyze the effect of automation on detection failures, it is necessary to analyze how automation can affect human operators' situation awareness.

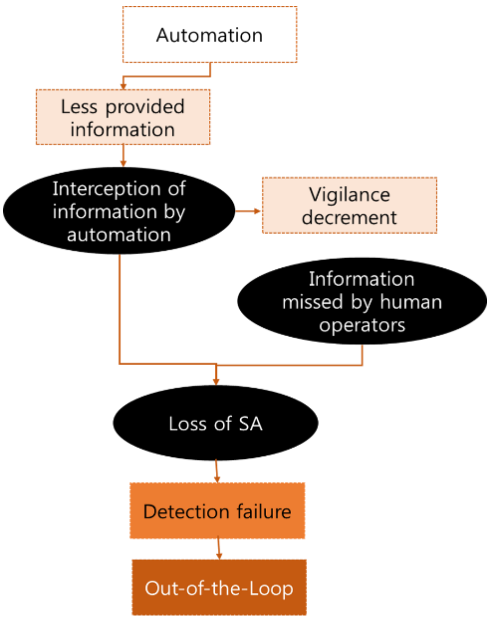

Fig. 1 Relationship between the loss of SA and OOTL.

2.3 Level of ostracism

Human operators' tasks in NPPs require human cognitive functions such as monitoring instruments and measuring the values or the statuses of certain types of equipment, understanding a situation and making a decision, and implementing appropriate responses [15]. According to what types of cognitive functions are replaced by the automation, the LOA is extended from manual to full automation [16]. However, the LOA classifications provide a mixed description of two different dimensions: which types of automatic functions are involved as regards computers, and how many tasks are supported by the automatic functions. Thus, four levels of classification which only focus on the differences in supported automatic functions are obtained in this study based on the existing LOA definitions.

- Level 1: Manual Operation
  This refers to no automation. Operators manually perform all functions and tasks.
- Level 2: Operation by Consent
  This refers to situations in which operators monitor closely and approve actions to complete a step and move to the next step.
- Level 3: Operation by Exceptions
  This means that operators may intervene to make critical decisions in specific situations or under certain circumstances.
- Level 4: Autonomous Operations
  This refers to fully automated operation. Operators simply monitor the performance or do nothing.

Based on the above classification, the method used to observe information can also differ according to the types of automated procedures. The degree of difficulty in obtaining information from the automated system is defined as the Level of Ostracism (LOO). It is shown in Table 1. In LOO 1, human operators are given all information about tasks and indicators, and human operators' actions are necessary to move on to the next step. The information is provided until the human operators fully recognize it. LOO 2 describes an automated procedure that moves on to the next step after an automatic execution. However, human operators can stop the progress of the procedure to receive information about tasks and indicators. The LOO 3 automated procedure gives information only about the tasks, and the procedure moves on to the next step after the automatic execution in the same way as LOO 2, but human operators cannot stop the progress of the automated procedure. They can only ask about information about tasks and indicators. The LOO 4 automated procedure proceeds to the next step automatically without providing any information about tasks or indicators. Human operators never obtain information from the automated procedure.

Human operators' additional actions may be required for SA when they use an automated procedure having a certain ostracism level. In other words, the human operators' SA can vary according to how much human operator effort is needed to receive the information.

Table 1 Level of Ostracism

Level	Description
1	Human operators can receive information about tasks and indicators given by the automated procedure without time constraint.
2	Human operators can receive information about tasks and indicators given by the automated procedure for a certain duration before automatically moving on to the next step.
3	The automated procedure automatically proceed to the next steps with only providing information about tasks. Nevertheless, human operators can acquire the information when they ask it.
4	The automated procedure automatically proceed to the next steps without providing any information. Human operators do not have any way to acquire the information from the automated procedure.

2.4 Experiments

An experiment was conducted to estimate the validity of the proposed LOO. There are several hypotheses stating that a high LOO induces low accuracy of SA. This refers to a certain relationship between the LOO and the accuracy of a human operator's SA. Thus, it can be proved that the suggested LOO is valid if the LOO and the accuracy of SA are meaningfully linked.

2.4.1 Experimental design

Nine graduate students majoring in nuclear engineering participated in this experiment. They monitored the state of indicators through a compact nuclear simulator (CNS) screen according to a given procedure. A loss of coolant accident (LOCA) emergency operation procedure-based scenario was selected, and the relationships between seven plant statuses and the expected states of 18 indicators were analyzed, as shown in Table 2. All participants were trained to adapt to the CNS screen, and they were asked to conduct their tasks as rapidly as they could because the situation was assumed to be an emergency operation.

Table 2 Relationships between plant status and the expected states of indicators for the experiment

Indicators		Plant status and the expected state of indicators													
		Coolant Leakage		Aggressive secondary cooling		PSV rupture		RCP operation fail		LOCA in CTMT		Core exposure		Failure of isolation of LOCA location	
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
1	PRZ pressure	**Dec**	Stb	**Dec**	Stb										
2	SIAS	**On**	Off	**On**	Off	**On**	Off								
3	HPSI	**On**	Off	**On**	Off										
4	LPSI	**On**	Off	**On**	Off										
5	CTMP pressure	**Inc**	Stb												
6	RCP operation							Off	**On**						
7	RCS isolation valve									Op	**Cl**				
8	CCW radiation									On	**Off**				

9	RVUH valve									Op	**Cl**				
10	CCW tank level									Inc	**Stb**				
11	CIAS					**On**	Off								
12	CTMT isolation valve											Op	**Cl**		
13	CSAS											On	**Off**		
14	PRZ pressure													Dec	**Stb**
15	PRZ level													Dec	**Stb**
16	CV sump level													Inc	**Stb**
17	Aux. sump level													Inc	**Stb**
18	MSIV													Op	**Cl**

Inc: increased, Stb: stable, Dec: decreased, Op: opened, Cl: closed

Three types of automated procedures were designed according to the LOO classification. All three types of automated procedures were designed to provide information about the tasks, the indicators the participants should monitor, and information about the states of the indicators. The participants could monitor the state of the indicator using both the CNS screen and the automated procedure. Participants using the LOO1 automated procedure press a button to move on to the next step. Participants using the LOO 2 automated procedure observe the information about tasks and indicators within 25-35 seconds before the procedure moves on to the next step automatically. The participants who do not obtain the information can stop the progress of the procedure. Participants using the LOO 3 automated procedure are given the information about the tasks for about 25-35 seconds before the procedure moves on to the next step automatically. If they miss the information provided by the procedure, they can ask for it by searching through the previous steps, but they are not allowed to stop the progress of the procedure. All of the automated procedures were designed to provide four items of incorrect information about the states of the indicators, thus, the error probability of the automated procedures was assumed to be 0.22. Eight participants selected one procedure and were required to observe the bold-type information shown in Table 2.

2.4.2 Results and Discussion

The results of the experiment were analyzed using the Situation Awareness Control Room Inventory (SACRI), which is an interruptive questionnaire-technique-based SA measurement method commonly used in the nuclear field [17,18]. The SACRI enables the measurement of levels 1, 2, and 3 SA according to questions requiring the participants to answer. In this experiment, participants were required to answer questions to measure the level 1 SA, which concerns the participants' ability to perceive elements in the current situation, and their answers were analyzed. The accuracy of the SA and the LOO of the three designed automated procedures were calculated as shown in Table 3. The result of a linear regression analysis (R^2=0.8612) are shown in Fig. 2. From the ANOVA results, it appears that the ostracism rate and the accuracy of SA have a statistically meaningful correlation because the null hypothesis, stating that there is no relationship between the ostracism rate and human performance, was rejected ($F_{(2,6)}=40.052 > F_{0.05(2,6)}=5.143$). Therefore, it can be said that the higher the LOO is, the lower the accuracy of SA will be under a 95% confidence level.

Table 3 Measured accuracy of SA according to the different LOO of the automated procedures

Level of Ostracism	1	2	3
	0.90386	0.87610	0.64882
Accuracy of SA	0.95513	0.93231	0.62492
	0.94231	0.91047	0.73336
Average of the accuracy of SA	0.93377	0.90629	0.66903

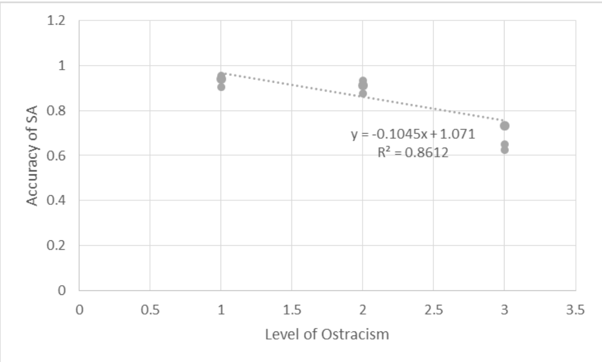

Fig. 2 Result of the linear regression analysis.

3 Determination of the optimized automation rate

3.1 Relationship between LOA & LOO

We can select the optimized automation level by suggesting combinations of the appropriate level of automation for multiple tasks considering both the positive and negative effects of automation. Thus, how the automation can reduce the human operators' load and induce the loss of situation awareness should be considered at the same time. Among various classifications of the LOA, we simplified them such that they only focus on the differences in the supporting automatic functions, as mentioned in section 2.3. This simplified LOA can be connected to the LOO, which is classified according to the difficulty in obtaining information according to differences in the opportunities to observe the information. The LOA is the classification about how the automation provides the information to reduce the human operators' cognitive load and the LOO is the classification about how human operators receive the information from the automation. By focusing on how the information is provided by the automation and received by human operators, the relation of LOA and LOO can be easily defined regardless of the various scales of the suggested LOA. The relationship between the simplified LOA and LOO is defined as shown in Table 4. For example, LOA 1 is a completely manual system, that is, human operators have no support when conducting their cognitive tasks, such as monitoring tasks, decision making, or execution, or even moving onto the next step on during the procedure. Human operators do not receive any help from automation, at the same time, they are not interrupted at all by the automation.

Table 4 Relationship between LOO and LOA

LOO		LOA	
1	Human operators can receive information given by the automation system without time constraint.	1	Operators check all the inputs and select one by comparing a criterion suggested in a procedure and only select one output (manual).
		2	Automation suggests one datum by comparing all of the environmental variables with a criterion. One output is selected when operators conduct an action with meaningful consent.
2	Human operators can receive information given by the automation system for a certain duration before automatically moving on to the next step.	3	Automation suggests one datum by comparing all of the environmental variables with a criterion. One output is selected unless operators do not veto it during the suggested time.

3	The automation automatically proceed to the next steps without providing any information. Nevertheless, human operators can acquire information when they ask it without stopping the automation system.	4	One output is selected when the automation (CPS) selects one datum by comparing all of the environmental variables with a criterion.
4	The automation automatically proceed to the next steps without providing any information. Human operators do not have any way to acquire the information except for stopping the automation system.		

In other words, LOA 1 provides the tasks and all of the information that the human operators demand. LOA 2 is an automation system which supports the monitoring function of human operators, thus, LOA 2 provide a minimum amount of information which is expected to be needed by human operators. After human operators perceive the information, they manually move the procedure onto the next step, as they do in the case of LOA 1. LOA 1 and LOA 2 have different features to provide information to human operators, however, from the human operators' point of view about who receives the information, they have same chance to obtain the information required by the procedure until they attempt to hand over the sequences themselves. Thus, both LOA 1 and LOA 2 are clearly related to LOO 1. On the other hand, LOA 4 is full automated, indicating that human operators have no cognitive task load to complete their tasks. LOA 4 does not ask human operators to participate to conduct the tasks, but LOA 4 can share information which improves the human operators' SA. LOA 4 does not assign any role to human operators. Also, it moves onto the next step automatically.

However, if it provides information about tasks and task-related results for at least what it has done, this LOA 4 is then related to LOO 3. If LOA 4 does not provide any information, this LOA 4 is related to LOO 4. Thus, both LOO 3 and LOO 4 are clearly related to LOA 4. This suggestion can be applied to various scales of LOA, which have been suggested by various researchers. Examples of the expansion of suggesting a relationship between LOO and LOA to a ten-scale version and a five-scale version of LOA are shown in Table 5 and Table 6, respectively.

Table 5 Comparison of the suggested LOO and the ten-scale version of classification of the LOA

LOO	LOA	The ten scales of LOA	
1	1	1	Manual control: The human performs all tasks including monitoring the state of the system, generating performance options, decision making, and implementing it.
		2	Action support: The system assists the operator with performance of the selected action, although some human control actions are required.
		3	Batch processing: Although the human generates and selects the options to be performed, they then are turned over to the system to be carried out automatically.
	2	4	Shared control: Both the human and the computer generate possible decision options. The human retains full control over the selection, but carrying out the action is shared.
		5	Decision support: The computer generates a list of decision options that human can select from, or the operator may generate his or her own options. Once the human selected an options, it is turned over to the computer to implement.
		6	Blended decision: The computer generates a list of decision options and carries out if the human consents. The computer then carries out the selected action.
		7	Rigid system: The computer presents only a limited set of actions to the operator. Operators select from among this set and cannot generate any options.
		8	Automated decision making: The system selects the best options to implement and carries out that action.
2	3	9	Supervisory control: The system generates options, selects the options to implement and carries out that action. The human mainly monitors the system and intervenes if necessary.

3 / 4	4	10	Full automation: The system carries out all actions. The human is completely out of the control loop and cannot intervene.

Table 6 Comparison of the suggested LOO and the five-scale version of classification of the LOA

LOO	LOA	The five scales of LOA	
1	1	1	Manual operation: No automation
		2	Shared operation: Automatic performance of some functions or tasks
	2	3	Operation by consent: Automatic performance when directed by operators to do so, under close monitoring and supervision
2	3	4	Shared control: Essentially autonomous operation unless specific situations or circumstances are encountered
3 / 4	4	5	Decision support: Fully autonomous operation. System or function cannot normally be disabled, but may be started manually

3.2 Selection of the optimized combination of LOAs

A procedure involves many steps, and most of the steps contain more than one task. Each task can have different LOA and LOO properties according to the characteristics of the task, such as its difficulty and importance. That is, one procedure which is a multi-task job has various combinations of LOA and LOO.

We should select an appropriate LOO for each task for a multi-task step and select a combination of LOA following the suggested relationship between LOA and LOO. In this process, the most important point is to determine the LOO of each task. There are several suggestions for determining an appropriate combination of LOOs for tasks. The decision should be made by an expert who understands the meaning, difficulty and importance of the tasks. They would likely apply automation of low LOO to high-priority tasks, or they would apply automation of the highest LOO as long as human operators can maintain the minimum opportunity or ability to diagnose the situation. After determining the LOO, it would be better to select the highest LOA belonging to the decided LOO for the best performance. This is a qualitative estimation method to optimize the combination of the level of automation following the decision of an appropriate LOO combination according to the experts' opinions.

The advantage of this qualitative optimization strategy is that it can reflect the characteristics of not only the tasks but also of the human operators, such as their technical skills, their knowledge or experience, and non-technical skills such as their emotional states or environmental conditions. The qualitative optimization method can suggest the adaptive optimization of the automation rate. However, determining the LOO according to experts' opinions represents weakness of the suggested strategy. If it is possible to estimate the permissible limit of human operators' loss of SA quantitatively, this will enable us to derive an analytically optimized combination of the automation level.

4 Conclusion

Since automation was introduced, it has been found that an excessive introduction of automation generates the OOTL problem. The most negative aspect of the OOTL performance problem in NPPs is that the information received by human operators is reduced. We analyzed two information interrupting factors that reduce the opportunity to obtain information and defined the degree of difficulty in obtaining information as the Level of Ostracism (LOO). We also conducted an experiment to evaluate the validity of the suggested LOO. Results were verified by the discovery of a certain relationship between the LOO and the accuracy of SA. Based on the suggested LOO, a qualitative optimization strategy for determining the automation level was proposed. The qualitative optimization method to determine the automation level provides the relationships between the existing LOA and the suggested LOO, which is the degree of difficulty in obtaining information according to the LOA. We can select an appropriate combination of the LOA and LOO for each task in as multi-task job. This is expected to be useful for determining the optimized combination of the level of automation, as experts who select an appropriate combination of LOO and LOA can consider the characteristics of the individuals' technical skills and non-technical skills, or the environmental condition.

References

[1] ENDSLEY, M. R., and KIRIS, E. O.: The Out-of-the-Loop Performance Problems and Level of Control in Automation. Human Factors. 37, 381-394, 1995.

[2] KABER, D. B., and ENDSLEY, M. R.: Out-of-the-Loop Performance Problems and the Use of In-termediate Levels of Automation for Improved Control System Functioning and Safety. Process Safety Progress. 16, 126-131, 1997.

[3] EPRATH, A. R., and YOUNG, L. R.: Monitoring vs. Man-in-the-Loop Detection of Aircraft Control Failures, in: Rasmussen, J., Rouse, W. B., (Eds.), Measurement of Human Resources. Taylor and Francis, London, pp.143-154, 1981.

[4] SHERIDAN, T. B., and VERPLANK, W. L.: Human and Computer Control of Undersea Teleopera-tors. MIT Man-Machine Laboratory, Cambridge, MA, 1978.

[5] PARASURAMAN, R., and SHERIDAN, T. B.: A Model for Types and Levels of Human Interaction with Automation. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans. 30, 286-297, 2000.

[6] WICKENS, C. D., and KESSEL, C.: Failure Detection in Dynamic Systems, in: Rasmussen, J., Rouse, W. (Eds.), Human Detection and Diagnosis of failures. Plenum Press, New York, pp.155-169, 1981.

[7] WARM, J. S., MATTHEWS, G., and FINOMORE, V. S.: Vigilance, Workload, and Stress. In P. A. Hancock & J. L .Szalma (Eds.), Performance under stress pp.116-141, 2008.

[8] PARASURAMAN, R.: Vigilance, Monitoring and Search In J.R. Boff, L. Kaufmann & J.P. Thomas (Eds.) Handbook of Human Perception and Performance, Vol.2, Cognitive Processes and Performance pp. 41–49, 1986.

[9] HELTON, W. S., KERN, R. P., and WALKER, D. R.: Conscious Thought and the Sustained Attention to Response Task. Consciousness and Cognition, 18, pp.600-607, 2009.

[10] HELTON, W. S., and RUSSELL, P. N.: Working memory load and the vigilance decrement. Experimental Brain Research, 212, pp.429-437, 2011.

[11] KIBBLE, M.: Information Transfer from Intelligent EW Displays. Proceedings of the Hu-man Factors Society, 32nd Annual Meeting, Santa Monica, CA: Human Factors Society, 1988.

[12] FURUKAWA, H., INAGAKI, T., and NIWA, Y.: Operator`s situation awareness under different levels of automation; Evaluations through probabilistic human cognitive simulation. IEEE Explore, 1319-1324, 2000.

[13] LEE, J. D.: Human Factors and Ergonomics in Automation Design, in: Salvendy, G. (Ed.), Handbook of Human Factors and Ergonomics, third ed. Wiley, Hoboken, NJ, pp.1570-1596, 2006.

[14] O`HARA, J., GUNTHER, B., and GURIDI, G. M.: The Effects of Degraded Digital Instrumentation and Control Systems on Human-system Interfaces and Operator Performance: HFE Review Guidance and Technical Basis, Technical Report BNL-91407-2010, 2010.

[15] ENDSLEY, M. R., and KABER, D. B.: Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics. 42, 462-492, 1999.

[16] KABER, D. B., and ENDSLEY, M. R.: The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. Theoreti-cal Issues in Ergonomics Science. 5, 113-153, 2004.

[17] HOGG, D. N., FOLLESO, K., STRAND-VOLDEN, F., and TORRALBA, B.: Development of a situation awareness measure to evaluate advanced alarm systems in nuclear power plant control rooms, Ergonomics, 38, pp.2394-2413, 1995.

[18] LAU, N., SKRAANING, G., EITRHEIM, M. H. R., KARLSSON, T., NIHLWING, C., and JAMIESON, G. A.: Situation Awareness in Monitoring Nuclear Power Plants – The Process Overview Concept and Measure, HRP-954, 2011.