[UCI]I804:24011-200000489730

2021년 8월
석사학위 논문

An Experimental Analysis of Human Performance Differences Depending on Simulator Complexity

조선대학교 대학원
원자력공학과
최 정 훈

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이 논문을 공학 석사학위신청 논문으로 제출함

2021년 4월

조선대학교 대학원

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2021년 5월

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ABSTRACT

시뮬레이터 복잡성에 따른 인적 수행도 차이에 대한 실험적 연구

조선대학교 대학원
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원자력발전소의 안전성을 종합적으로 평가하는 확률론적안전성평가(Probablistic Safety Assessment)에서 인적요소로 인해 발생 가능한 리스크를 체계적으로 분석하고 예측하는 인간신뢰도분석(Human Reliability Analysis, HRA)은 매우 중요한 요소이다. 이를 위해 타 산업에서의 데이터나 전문가의 판단 또는 훈련용 시뮬레이터 연구 등으로 인간신뢰도 데이터를 수집하여 인적오류 확률을 추정하려고 시도해왔다. 현재, HRA 분야에서의 중요 연구는 Full-Scope 시뮬레이터에서 실제 운전원의 데이터를 수집하는데 중점을 두고 있다.

본 연구는 INL에서 개발한 SHEEP을 기반으로 Full-scope 데이터 수집 연구를 지원하는 방법을 제안하는 프로젝트의 일부이다. 벤치마크 실험에서 보다 단순화된 시뮬레이터(예: Rancor Microworld)와 복잡한 시뮬레이터(예: Compact Nuclear Simulator)를 사용할 때의 인적 수행도를 비교한다. 무작위 요인 실험 설계는 시뮬레이터 유형과 시나리오 유형 두 가지 독립 변수로 설정했다. 4가지 인적 수행도 즉, 1) 시간, 2) 오류, 3) 작업량, 4) 상황 인식을 측정하였다. 그런 다음 두 시뮬레이터에서 수행할 몇 가지 시나리오(정상/비상)와 관련 절차서를 개발했다. 실험에서 수집된 데이터는 분산 분석(ANOVA) 테스트 및 상관 분석과 같은 여러 통계 분석 기법을 활용하여 인적 수행도를 비교하였다.

본 연구 결과는 단순화된 시뮬레이터와 학생 데이터를 기반으로 Full-scope 시뮬레이터 환경에서의 운전원의 인적 수행도를 유추하는 연구에 기여할 수 있을 것으로 기대된다.

I. Introduction

Lack of human performance data is a key factor in human reliability analysis (HRA) [1, 2]. Accordingly, several institutes and researchers have attempted to collect HRA data from different data sources, such as actual historical measurements, simulator studies, and expert judgments. Modern studies have predominantly focused on collecting data using full-scope simulators with actual operators. On the other hand, Idaho National Laboratory (INL) attempted to gather HRA data via the Simplified Human Error Experimental Program (SHEEP), which employs a simplified simulator and student participants. INL has considered implementing the SHEEP approach using simplified simulators such as Rancor Microworld and the Compact Nuclear Simulator (CNS) to complement—not replace—full-scope studies, as well as to primarily collect HRA data for estimating the nominal/basic human error probabilities needed in the HRA quantification process.

This study compares human performance when two types of simple simulators: a more simplified simulator (Rancor Microworld) versus a less simplified simulator (CNS) across benchmark experiments. A randomized factorial experiment design was developed with two independent variables: type of simulator and type of scenario. Four human performance measurements were selected: 1) time, 2) error, 3) workload, and 4) situational awareness. Several scenarios and related procedures to be simulated using both simulators were then developed. The data collected by conducting the experiments were analyzed using several statistical analysis methods, such as an analysis of variance (ANOVA) test and a correlation analysis.

II. SHEEP Framework

Fig. 1 shows the SHEEP framework, which represents an ongoing effort to provide additional data to support and complement full-scope studies. The framework consists of three steps: (1) identification of collectable HRA items from a simplified simulator, (2) Treatment of these HRA items based on experiments, and (3) integration of the data into a full-scope database for deployment in HRA methods.

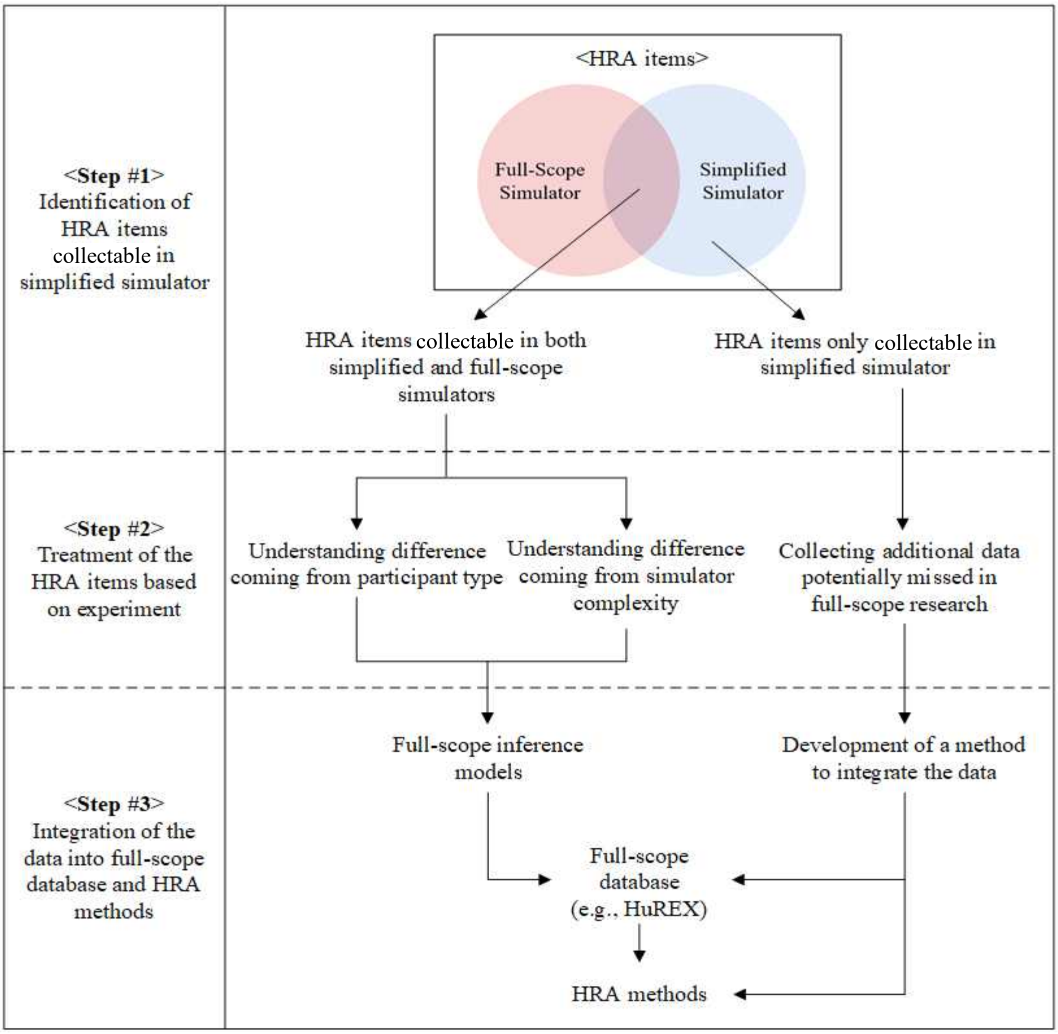


Fig. 1. SHEEP framework

The first step classifies all collectable HRA data items from any type of simulator into two groups: (1) collectable items from both simplified and full-scope simulators, and (2) items only collectable from simplified simulators. The second step suggests how experimentation can be used to treat the relevant HRA items classified in the first step. For HRA items collectable from both simplified and full-scope simulators, this step involves differentiating the participant type (i.e., operator vs. student) and simulator complexity (i.e., simplified vs. full-scope). The design of this study sets the stage for collecting the data needed to develop full-scope inference models in the next step. In the case of the HRA items that can only be collected in a simplified simulator, this step contributes to gathering new HRA data that are missed by full-scope simulators. The last step integrates experimental data obtained in the previous step into a comprehensive or full-scope database that could potentially be incorporated into HRA methods.

This paper mainly discusses how to treat HRA items that are collectable from both simplified and full-scope simulators. For these items, inference models are planned to be developed based on differences arising with respect to participant type and simulator complexity. Fig. 2 shows the detailed process of inferring full-scope data based on simplified simulator data. Error data from students and operators when using a less simplified simulator (e.g., CNS [3]) or a more simplified simulator (e.g., Rancor Microworld [4]) were collected through experiments. Then, by developing a method to define the gaps (1) between students and operators, (2) between the two simplified simulators, and (3) between the simplified simulators and a full-scope simulator, the operator data for the full-scope environment is inferred using the student data from the simplified simulators.

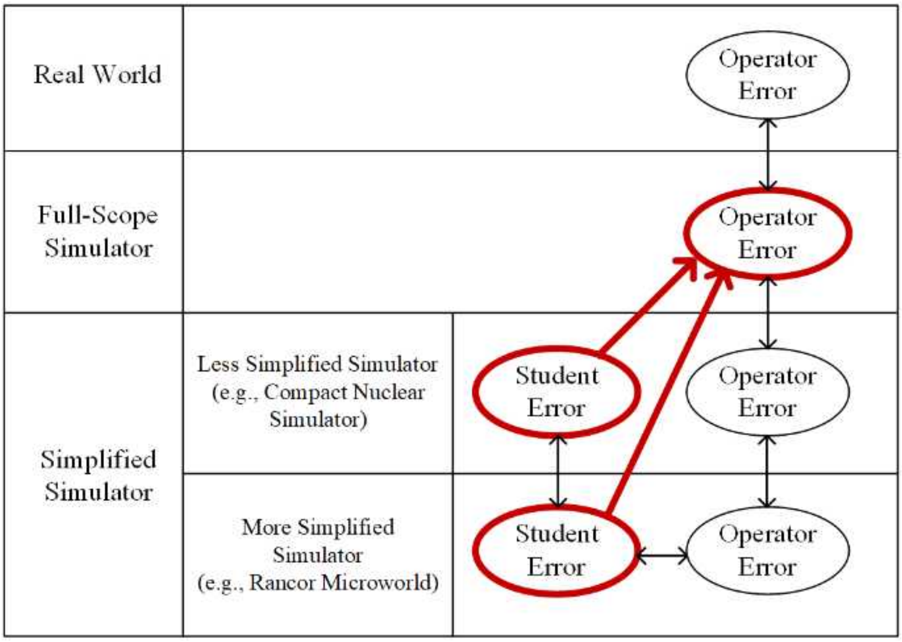


Fig. 2. Process to infer full-scope data based on simplified simulator data

III. Experimental Design

In previous studies [5, 6], human performance data to understand the differences between students and actual operators when using Rancor Microworld (i.e., a more simplified simulator) has been collected. This current study is about collecting human performance data based on the CNS (i.e., a less simplified simulator). Thereafter, the current data is compared with those collected in the previous studies, to enable a determination of the differences arising from simulator complexity. A randomized factorial experiment is used to compare the human performance between the two simplified simulators. Table 1 shows the experimental design, composed of two independent variables: ‘type of simulator’ and ‘type of scenario’. The details of the experimental design are described in the following sections.

Table 1. Randomized factorial experiment design

Type of scenario	Type of simulator	
	More simplified simulator (Rancor Microworld)	Less simplified simulator (CNS)
Non-event	Time Error Workload Situational awareness	Time Error Workload Situational awareness
Event	Time Error Workload Situational awareness	Time Error Workload Situational awareness

A. Independent Variables

1. Type of simulator

This variable is divided into two groups: a more simplified simulator (Rancor Microworld) and a less simplified simulator (CNS). The Rancor Microworld simulator is a simplified simulation environment that reproduces the important characteristics of real operations at nuclear power plants (NPPs) [4]. It has been used to examine theoretical and practical design related to process control, and it also provides a graphical user interface that allows researchers to manipulate the process control systems. The Rancor Microworld simulator was developed based on thermo-hydraulics, which follow a gamified Rankine cycle similar to a small modular reactor. Fig. 3 shows the interface for Rancor Microworld. It consists of three windows: 1) the Overview Window, 2) the Piping and Instrumentation Diagram Window, and 3) the Controls Window. The Overview Window displays general system information such as the alarm panel. Its integrated design informs operators when certain parameters fall outside their acceptable range. The Piping and Instrumentation Diagram Window shows parameters for items such as the steam generator’s pressure, if valves have been turned on and opened or pump operating status. Finally, the Controls Window applies to all controllable measures, such as sliders and buttons. CNS (see Fig. 4) [3] is a representative simulator that can be used in this study. As a simplified simulator developed by the Korean Atomic Energy Research Institute (KAERI), it is based on the Westinghouse 900MWe, 3-Loop pressurized water reactor (PWR). It is a simulator modeling the power plant 1st and 2nd systems and the containment container. Not only the Reactor Coolant System (RCS) of the primary system, but also the power system is modeled. Table 2 indicates the major differences between CNS and Rancor Microworld.

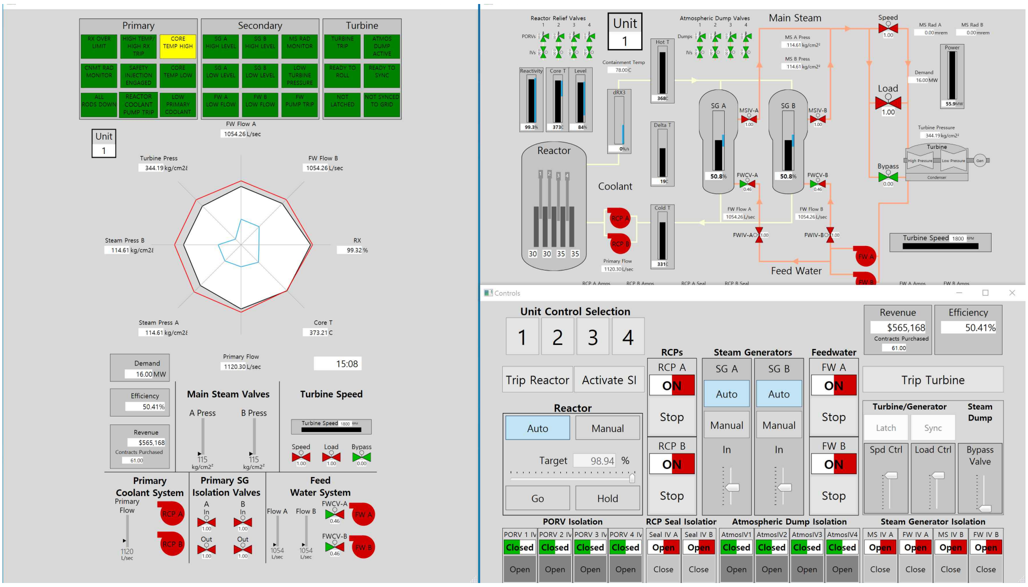


Fig. 3. Rancor Microworld interface screen

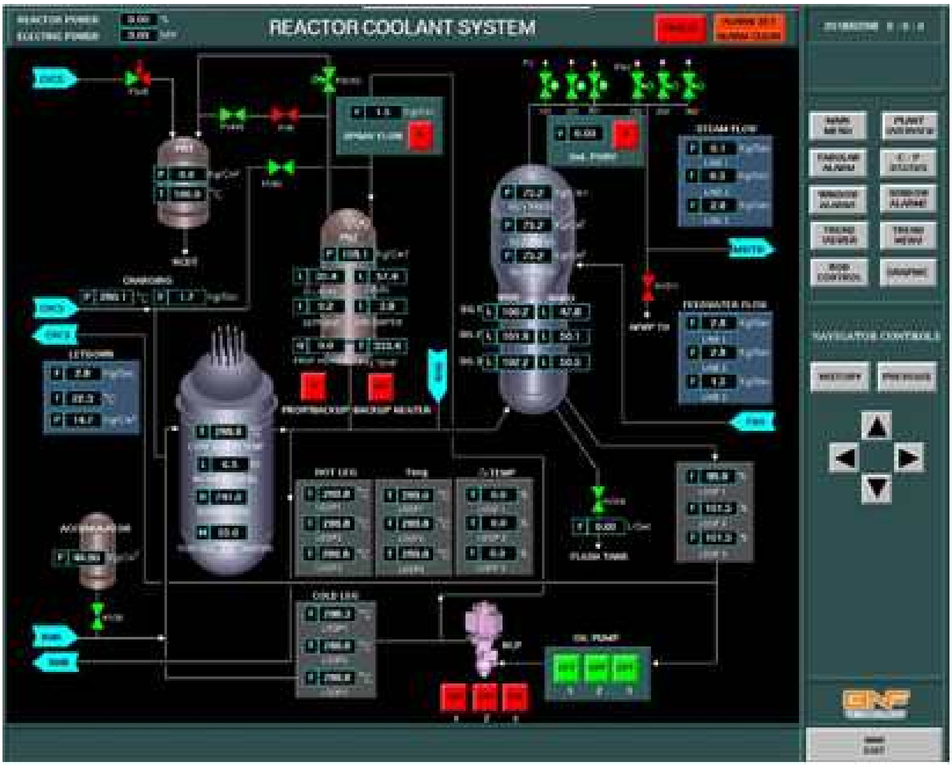


Fig. 4. CNS interface screen

Table 2. Comparison of simulator characteristics between Rancor and CNS

Characteristic	Comparison
System Complexity	Rancor Microworld < CNS
Task Complexity	Rancor Microworld < CNS
HSI Complexity	Rancor Microworld < CNS
Procedure	Rancor Microworld ≈ CNS
Training	Rancor Microworld ≈ CNS
Stress	Rancor Microworld ≈ CNS
Familiarity	Rancor Microworld ≈ CNS

2. Types of scenario

The types of scenarios are subdivided into non-event and event scenarios. Non-event scenarios are similar to the general operations usually performed during normal states, such as start-up, shutdown, or full-power operation. In these scenarios, participants may not feel as great a responsibility or as much time pressure in their work compared to event scenarios. On the other hand, event scenarios consist of critical actions that should be completed within a limited time frame that could positively or negatively affect the future state of the plant. Abnormal or emergency situations are examples of event scenarios.

B. Experimental Scenarios

Scenarios and related procedures to be simulated using CNS were developed for the experiment. These scenarios are relatively simple compared to those considered in full-scope studies. Table 3 lists the experimental scenarios, success criteria, and related procedures that were tested. Both non-events and events were simulated.

Each scenario is terminated when the participants complete a predetermined procedure or achieve a specific goal. Non-event scenarios end when the reactor power reaches a predetermined state (i.e., 0% or 50%). Event scenarios end when participants successfully perform all procedural steps or instructions, and parameters such as core temperature can be maintained at stable values.

Table 3. List of experiment scenarios and procedures

Type of scenario	Tittle	Description	Procedure	Success criteria
Non-event	Start-up operation (2% to 50%)	Increase reactor power from 2% to 50% in fully automatic mode	OP-001 (Start-up)	Reactor power = 50% No reactor trip during the operation
	Shut-down operation (100% to 2%)	Shut down the reactor from 100% to 2%(hot-standby) in fully automatic mode	OP-002 (Shut-down)	Reactor power = 2% No unintended reactor trip during the shutdown
Event	Steam generator tube rupture (SGTR) with failure indicator for the steam generator level	According to steam generator tube rupture, it is necessary to isolate damaged steam generator, maintain safety functions, and cool down the reactor coolant system temperature.	EOP-E-3 (SGTR)	Diagnosis of an initiating event or failure Isolation of damaged steam generator Reactor coolant system temperature < 200°C
	Loss of feedwater (LOFW)	Loss of feedwater pump, requires isolating the damaged steam generator, maintaining safety functions, and reducing the reactor coolant system temperature.	EOP-E-2 (LOFW)	Diagnosis of an initiating event or failure Reactor coolant system temperature < 200°C

C. Human Performance Measurements

In this experiment, four human performance measurements−1) time, 2) error, 3) workload, and 4) situational awareness, are taken for each scenario. This section details each of these measurements.

1. Time

This human performance measurement encompasses the average time required to complete a step, instruction, and task. A procedure consists of steps that are composed of instructions, which generally include one or more task(s). Fig. 5 shows an example of the procedure format. “Perform core cooling using Bypass Valve” is regarded as the step, “Adjust the Bypass Valve properly to keep the core temperature below 400°C” is an instruction, and “Open the Bypass Valve by 10.0%” is a task.

Rancor Microworld Procedure		Revision #: 01
OP-002	Shutdown Operation	Page #: 4/8
[Step]	4. Perform core cooling using Bypass Valve	
4.1. Adjust the Bypass Valve properly to keep the core temperature below 400°C. • Open the Bypass Valve by 10.0%. 4.2. If the Bypass Valve is open at 10.0%, move to step 5.		

Fig. 5. Example of the procedure format

2. Error

The error rate was calculated by dividing the number of errors by the total number of tasks in each scenario. An error is defined as occurring whenever an operator's task performance deviates from the expected actions. Errors include errors of omission (EOOs) and errors of commission (EOCs). EOOs are caused by omitting a task, whereas EOCs correspond to selection errors (e.g., selecting the incorrect control), errors of sequence (e.g., conducting tasks in incorrect order), time errors (e.g., performing an action too early or too late), or qualitative errors (e.g., too little or too much adjustment) [2].

To determine errors, this study applied the same rules and analysis categories as suggested in the HuREX project [7]. With regard to the rules, if a participant commits an error but recovers from it later, this experiment still counts it as an error. Regarding the analysis categories, the errors counted in each scenario are categorized according to the error types defined in the HuREX framework. Fig. 6 shows an example of how errors are counted based on the HuREX framework.

Event Class	Scenario	Type of Error	Student #1		Student #2		Student #3		Student #4	
			Number of errors	Total	Number of errors	Total	Number of errors	Total	Number of errors	Total
Non-event	Start-up (#1)	RP-Step (EOC)	2	3	-	0	-	1	-	0
		Ex-Continuous (EOC)	-		-		1		-	
		Ex-Dynamic (EOC)	1		-		-		-	
		RP-Step (EOO)	-		-		-		-	
	Shutdown (#2)	Ex-Continuous (EOC)	-	0	-	0	-	0	-	0
		Ex-Dynamic (EOC)	-		-		-		-	
	Start_up with manual rod control (#3)	Ex-Dynamic (EOC)	2	2	-	0	-	1	1	1
		RP-Step (EOC)	-		-		1		-	
		RP-Step (EOO)	-		-		-		-	
		RP-Procedure (EOC)	-		-		-		-	
		OT-Manipulation (EOC)	-		-		-		-	
		Ex-Continuous (EOO)	-		-		-		-	
		Ex-Continuous (EOC)	-		-		-		-	
	Start-up with manual feedwater flow control (#4)	Ex-Continuous (EOC)	3	3	3	3	-	0	2	2
		Ex-Continuous (EOO)	-		-		-		-	
		Ex-Dynamic (EOC)	-		-		-		-	
		RP-Step (EOC)	-		-		-		-	
		OT-Manipulation (EOC)	-		-		-		-	

Fig. 6. Example of how errors are counted based on the HuREX framework

3. Workload

This study considers the Modified Cooper-Harper (MCH) rating scale [8] to estimate workload. The MCH rating scale was originally developed by the aviation industry to estimate operators' physical and psychological workloads. Additionally, it provides design recommendations based on its rating scale. After each scenario, the workloads are evaluated based on responses to the questionnaires shown in Fig. 7. In addition, an alternative approach to estimate workload is to use an eye-tracker. Certain studies [9, 10] indicate a relationship between blinking rate and cognitive workload; however, this study did not consider this relationship within the research.

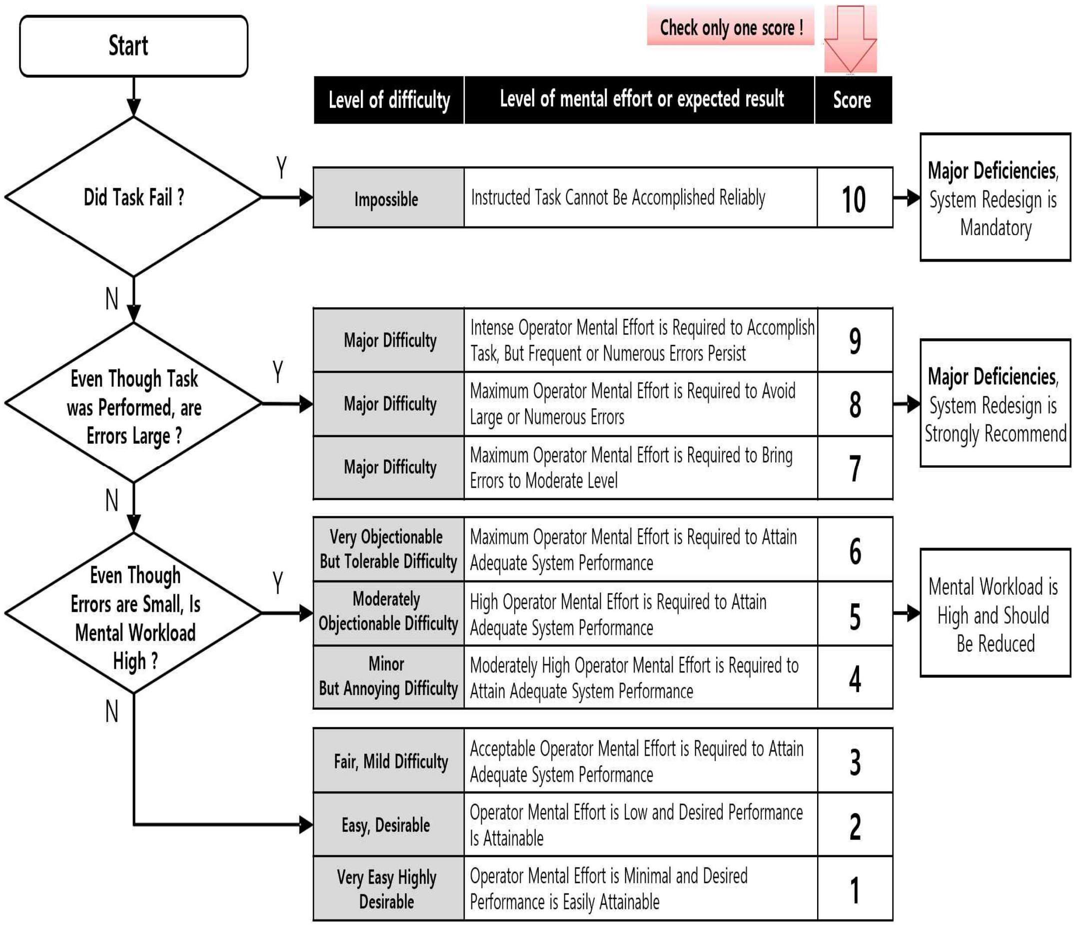
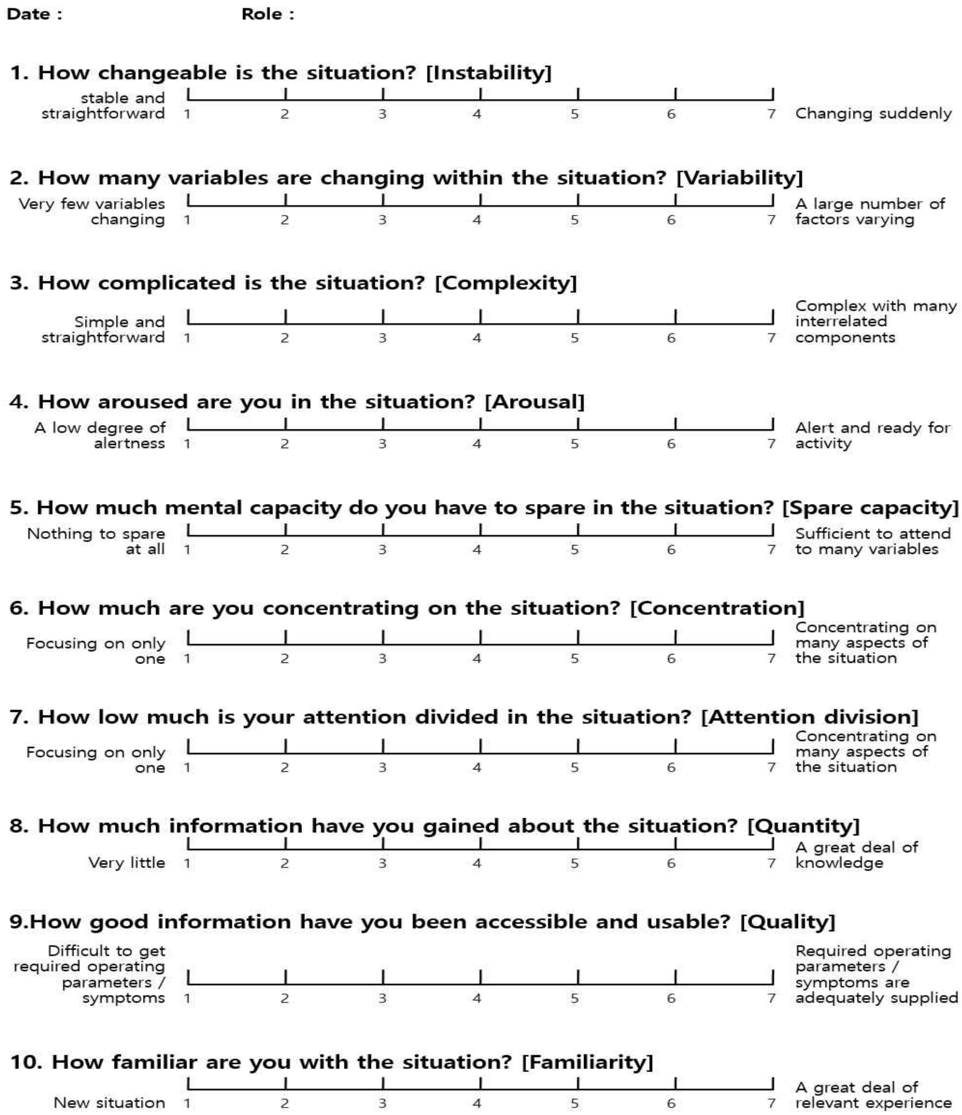


Fig. 7. Questionnaire used for the MCH rating scale

4. Situational awareness

Situational awareness indicates the perception of elements in an environment within a volume of time and space, which involves comprehending the meaning of the situation and projecting the status of the elements in the near future [11]. In this study, the Situational Awareness Rating Technique (SART) [12] was used to estimate subjects' situational awareness. Fig. 8 shows the questionnaire used for the SART rating scale.



Date : **Role :**

1. How changeable is the situation? [Instability]
stable and straightforward 1 2 3 4 5 6 7 Changing suddenly

2. How many variables are changing within the situation? [Variability]
Very few variables changing 1 2 3 4 5 6 7 A large number of factors varying

3. How complicated is the situation? [Complexity]
Simple and straightforward 1 2 3 4 5 6 7 Complex with many interrelated components

4. How aroused are you in the situation? [Arousal]
A low degree of alertness 1 2 3 4 5 6 7 Alert and ready for activity

5. How much mental capacity do you have to spare in the situation? [Spare capacity]
Nothing to spare at all 1 2 3 4 5 6 7 Sufficient to attend to many variables

6. How much are you concentrating on the situation? [Concentration]
Focusing on only one 1 2 3 4 5 6 7 Concentrating on many aspects of the situation

7. How low much is your attention divided in the situation? [Attention division]
Focusing on only one 1 2 3 4 5 6 7 Concentrating on many aspects of the situation

8. How much information have you gained about the situation? [Quantity]
Very little 1 2 3 4 5 6 7 A great deal of knowledge

9.How good information have you been accessible and usable? [Quality]
Difficult to get required operating parameters / symptoms 1 2 3 4 5 6 7 Required operating parameters / symptoms are adequately supplied

10. How familiar are you with the situation? [Familiarity]
New situation 1 2 3 4 5 6 7 A great deal of relevant experience

Fig. 8. Questionnaire used for the SART rating scale

D. Subjects

In this experiment, 36 participants contributed. There were 20 participants in the experiments using Rancor Microworld, and 16 participants in the experiments using CNS. The participants consisted of licensed operators employed at Korean NPPs or participants having extensive experience in NPP operations.

E. Facility

The Rancor Microworld and CNS simulators were installed on a laptop solely dedicated to the experiments. This experiment can be performed regardless of whether a desk, chair, or power source is available. In addition, the laptop enables subjects to operate the simulators via a touch screen.

F. Data Acquisition

In this study, the majority of the data were collected through the questionnaires described earlier and through use of an eye-tracker (without considering the relationship between blinking rate and cognitive workload). Table 4 summarizes the data acquisition methods, their collectable items, and human performance measurements. All items acquired from each method were directly linked to human performance data. Additional data that may be helpful for understanding the analysis results and for compiling alternative methods to identify other significant results can also be derived.

Table 4. Summary of data acquisition methods, their collectable items, and human performance measurements

Method	All Items collected	Human performance
Questionnaires	· General information for each subject - Workload from MCH(See Fig. 7) - Situational awareness scores from SART(See Fig. 8)	· Workload · Situational awareness
Eye-tracker	· Video record · Gaze · Workload from blinking data	· Time · Error · Workload

G. Training

The training material prepared for each participant included the purpose of the experiment, a description of the simulators and their systems, possible scenarios, questionnaires, and practice sessions. Training for each participant lasted approximately two hours.

H. Data Analysis

Data collected from the experiments were analyzed in three ways. As a first step, statistical analysis methods were applied to the randomized factorial experiment design. An analysis of variance (ANOVA) test and a correlation analysis were performed to identify significant results between items in each independent variable.

IV. Result

This section discusses the analytical results regarding which differences in the human performance measurements can be traced back to the two independent variables (i.e., type of simulator and type of scenario), as well as how correlated human performance measurements are when using Rancor Microworld or CNS. Two statistical analysis methods, analysis of variance (ANOVA) and a correlation analysis, were applied to investigate these differences.

A. Results of ANOVA Test

An ANOVA test was performed on each human performance measurement, assessing the amount of variability between the group means (in the context of variation within groups), to determine whether the mean differences were statistically significant. Table 5 summarizes the results of the ANOVA test.

Based on the overall ANOVA results, several human performance measurements exhibited significant differences stemming from the type of simulator and type of scenario. Except for the MCH scores, all measurements were statistically different, regardless of the scenario type. For the non-event scenarios, all measurements indicated statistically significant differences. Except for the SART scores, all others indicated significant results for the event scenarios. Details regarding these results are presented in the following subsections.

Table 5. Summary of ANOVA test results

Human performance	Measurements	Independent variable					
		Total		Non-event		Event	
		F-value	P-value	F-value	P-value	F-value	P-value
Workload	MCH	0.001	0.970	10.9	0.001	10.2	0.002
Situational awareness	SART	26.9	0.000	44.4	0.000	1.6	0.211
Time	Average time to complete a task	239.2	0.000	469.8	0.000	322.5	0.000
Error	Error rate	25.4	0.000	14.5	0.000	16.8	0.000

1. Workload

The MCH scores were not significant based on the ANOVA test performed for all data, but were significant when event and non-event scenarios were considered separately. In particular, an interaction was observed in the ANOVA test results. When using Rancor Microworld, the average MCH score (3.2) measured in the non-event scenarios indicated a higher workload than that measured in event scenarios (3.03). On the other hand, the opposite result was observed when using CNS. The average MCH score (2.25) measured in non-event scenarios indicated a lower workload than that measured in event scenarios (4.00).

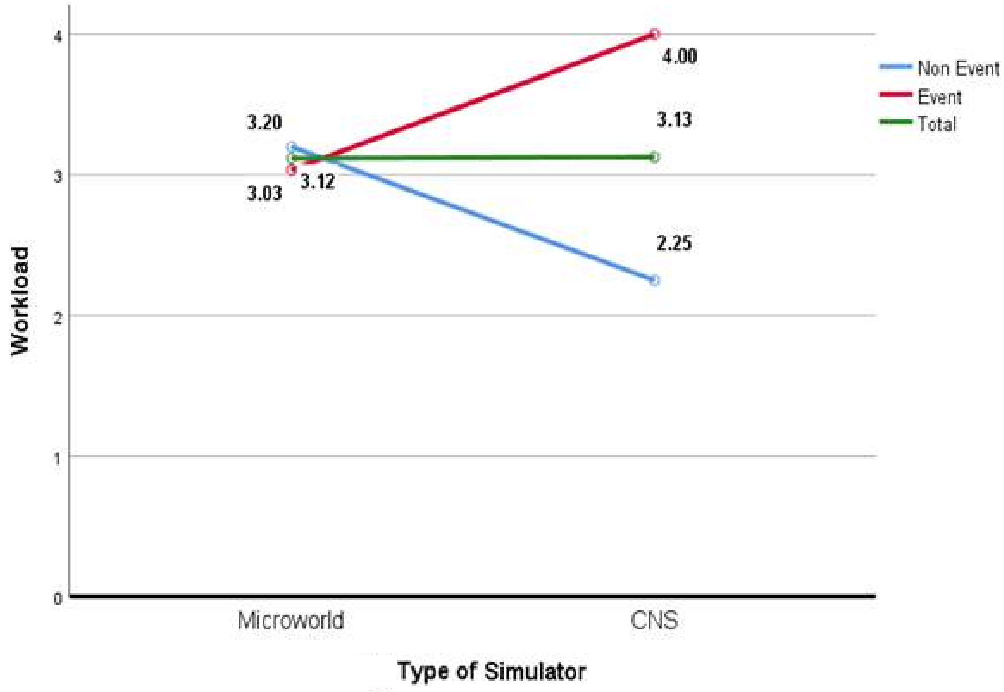


Fig. 9. Overall workload value trends

2. Situational awareness

The SART values were not significant for the simulator type for event scenarios but showed statistical differences in the variables for non-event scenarios and when both scenarios were considered. The SART values measured in non-event scenarios and for both scenarios exhibited higher values as the simulator complexity increased (transitioning from Rancor Microworld to CNS).

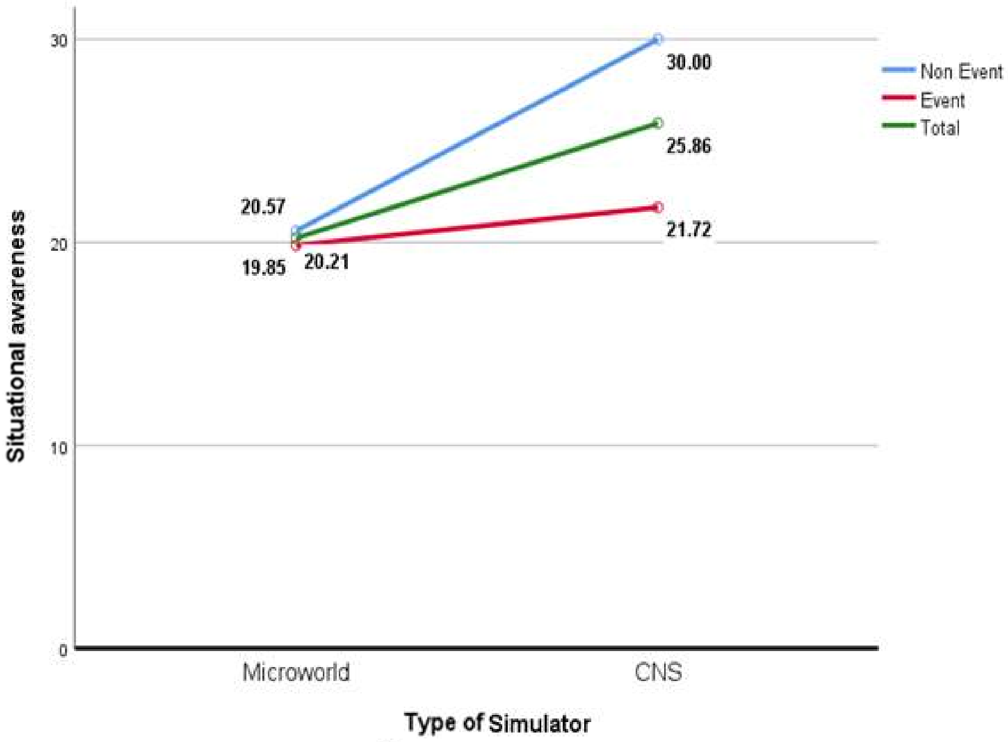


Fig. 10. Overall situational awareness value trends

3. Time

The time to complete a task values exhibited statistically significant results for the simulator type for event scenarios, non-event scenarios, and when both scenarios were considered. Higher values occurred as the simulator complexity increased (transitioning from Rancor Microworld to CNS).

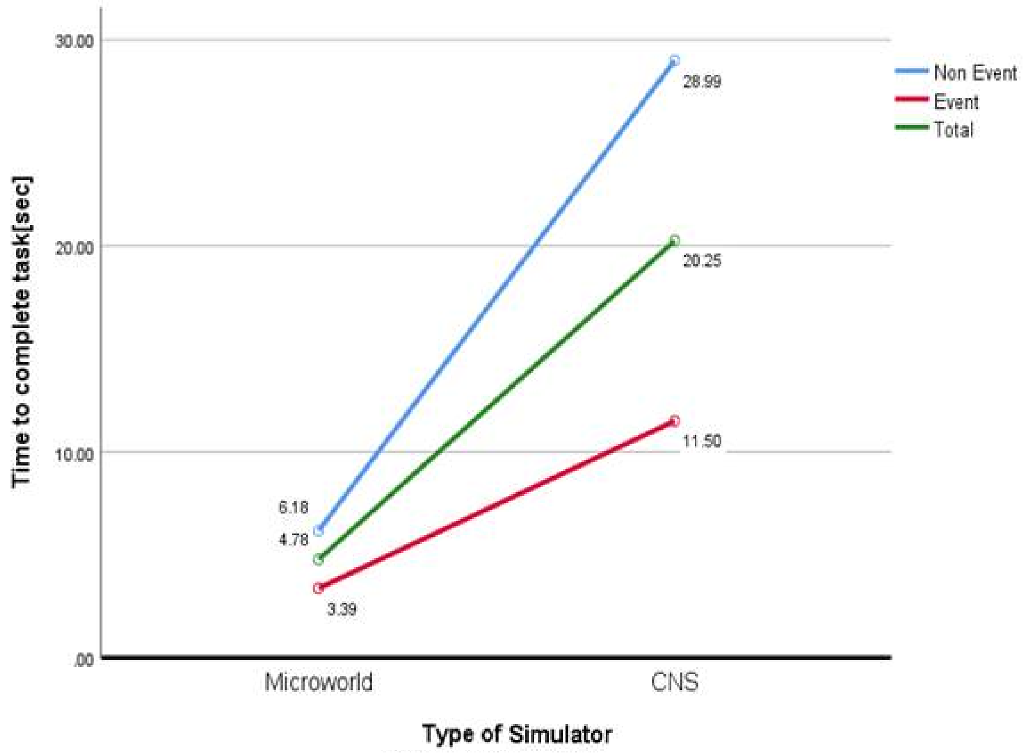


Fig. 11. Overall time value trends

4. Error rate

The error rate values exhibited statistically significant results for the simulator type for event scenarios, non-event scenarios, and both scenarios. Higher values were exhibited as the simulator complexity increased (transitioning from Rancor Microworld to CNS).

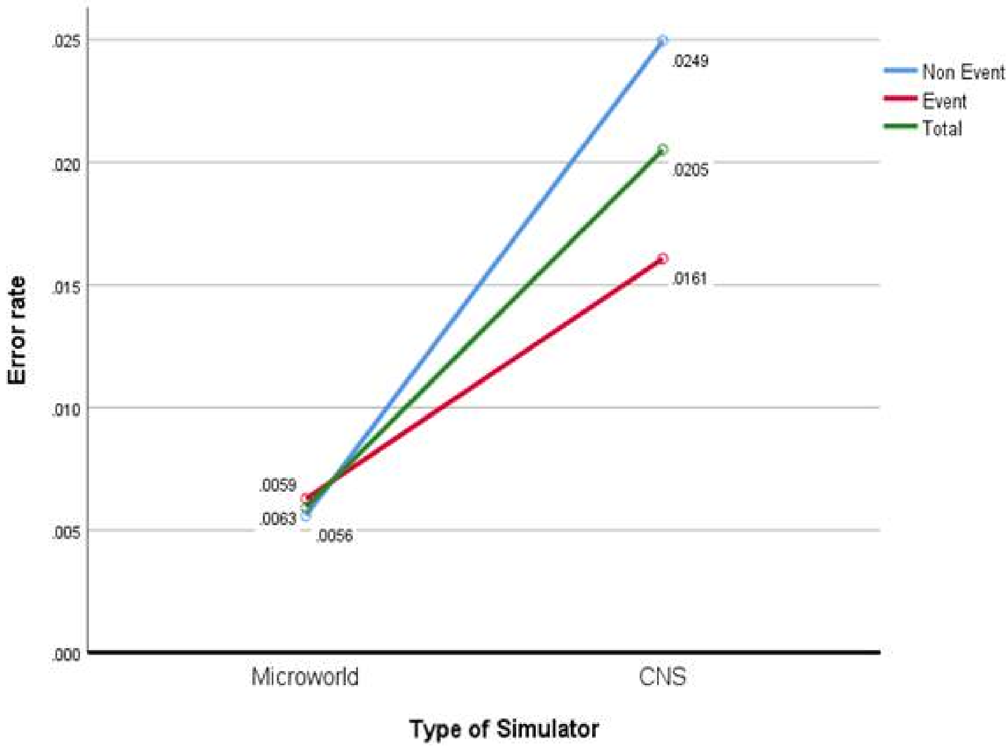


Fig. 12. Overall error rate value trends

B. Results of the Correlation Analysis

Through a correlation analysis, this section investigates how human performance measurements correlate to one another, depending on whether the participant is an operator or student. This method can help reveal relationships between the independent variables or show whether the variables are truly independent in the first place. The correlation coefficient *r* measures the direction and strength of a linear relationship. The Pearson product-moment correlation coefficient can be used to reveal correlations among the human performance measurements. The Pearson correlation indicates: (1) whether a statistically significant linear relationship exists between two continuous variables, (2) the strength of any linear relationship (i.e., how close the relationship is to being a perfectly straight line), and (3) the direction of a linear relationship (i.e., whether it is increasing or decreasing). Generally, a correlation coefficient of r = -1 indicates a complete relationship in the negative direction, while a value of r = 1 indicates a complete relationship in the positive direction. Moreover, for the correlation degree, coefficient values between ±0.50 and ±1 generally represent a strong correlation, whereas relationships between ±0.30 and ±0.49, as well as below +0.29, indicate moderate and low correlations, respectively.

Tables 6, 7, and 8 show the results of the correlation analysis for all data when using Rancor Microworld and when using CNS. The situational awareness had moderate or strong correlations within the significance level. There were no or low correlations between the error rate and the other human performance measurements. On the other hand, time had a significant correlation with the other performance measurements when using CNS.

Table 6. Results of correlation analysis (all participants)

	Workload	Situational awareness	Error	Time
Workload	1			
Situational awareness	-0.421**	1		
Error	0.048	0.184*	1	
Time	-0.186*	0.421**	0.496**	1

'*' shows the statistical difference considered within the 95% confidence level ($p<0.05$) as a result of the correlation analysis for the independent variable.

'**' shows the statistical difference considered within the 99% confidence level ($p<0.01$) as a result of the correlation analysis for the independent variable.

Table 7. Results of correlation analysis for operators when using Rancor Microworld

	Workload	Situational awareness	Error	Time
Workload	1			
Situational awareness	-0.375**	1		
Error	0.168	0.028	1	
Time	0.004	0.025	-0.07	1

‘*’ shows the statistical difference considered within the 95% confidence level ($p<0.05$) as a result of the correlation analysis for the independent variable.

‘**’ shows the statistical difference considered within the 99% confidence level ($p<0.01$) as a result of the correlation analysis for the independent variable.

Table 8. Results of correlation analysis for operators when using CNS

	Workload	Situational awareness	Error	Time
Workload	1			
Situational awareness	-0.569**	1		
Error	-0.004	0.095	1	
Time	-0.501**	0.383**	0.445**	1

‘*’ shows the statistical difference considered within the 95% confidence level ($p<0.05$) as a result of the correlation analysis for the independent variable.

‘**’ shows the statistical difference considered within the 99% confidence level ($p<0.01$) as a result of the correlation analysis for the independent variable.

V. Conclusion

This study attempted to identify human performance differences when using the Rancor Microworld and CNS simulators based on the SHEEP framework. This study compares human performance when using a more simplified simulator (Rancor Microworld) and a less simplified simulator (Compact Nuclear Simulator) across benchmark experiments. A randomized factorial experiment design was developed with two independent variables: type of simulator and type of scenario. Four human performance measurements were selected: 1) time, 2) error, 3) workload, and 4) situational awareness, were selected. Two scenarios and related procedures were then developed and simulated using both simulators. The data collected from the experiments were analyzed using two statistical analysis methods: an analysis of variance (ANOVA) test and a correlation analysis.

The result of comparing the operator human performance of Microworld and CNS shows that there was no significant difference in workload. However, situational awareness, average time to complete a task, and error rate showed higher values depending on the simulator complexity transiting from Rancor Microworld to CNS. As a result of the correlation analysis on the operator’s human performance, statistically significant results were drawn between the workload and the situational awareness, and the error rate and the situational awareness. In addition, it was analyzed that the average time it took to complete tasks correlated with the workload, the situational awareness, and the error rate.

The result of this study which has shown the difference in operator’s human performances according to the simulator complexity is expected to aid a study which will infer the operator’s human performance in a full-scope simulator environment. In other words, the result of this study will be helpful in studies that continue to collect additional data to better understand the gaps stemming from participant type (i.e. operators vs. students) and simulator complexity (i.e. simplified simulators vs. full-scope simulators).

VI. Acknowledgments

This study is supported by a project funded by INL, Standard Research Contract No. 231907. Chosun University acknowledges funding received from Idaho National Laboratory to support this research. I am grateful to Jooyoung Park for his assistance.

First and foremost, I would like to express my sincere and warm gratitude to my advisor, Prof. Jonghyun Kim, for his guidance, encouragement and support throughout my graduate study. and I would like to thank all members of Human Engineeing & Risk Analysis Lab and friends from Chosun University. I express my sincere gratitude and special thanks to Bumjun Park for his assistance.

References

[1] Park, J., et al., An experimental investigation on relationship between PSFs and operator performances in the digital main control room, Annals of Nuclear Energy, 101: p. 58-68, 2017.

[2] Swain, A. D., and H. E. Guttmann, Handbook of human-reliability analysis with emphasis on nuclear power plant applications, Final report, Sandia National Labs, 1983.

[3] Kwon, K.-C., et al., Compact nuclear simulator and its upgrade plan, 1997.

[4] Ulrich, T.A., The Development and Evaluation of Attention and Situation Awareness Measures in Nuclear Process Control Using the Rancor Microworld Environment, University of Idaho, 2017.

[5] Park, J., et al., Identification of Collectible Items in the Rancor Microworld Simulator Compared to Full-Scope Studies, International Conference on Applied Human Factors and Ergonomics, Springer, Cham, 2020.

[6] Kim, J., et al,. An experimental design on the use of rancor microworld simulator: a comparison of human performances between actual operators and students, Transactions of the Korean Nuclear Society Autumn Meeting, Goyang, Korea, 2019.

[7] Jung, W., J. Park, Y. Kim, S.Y. Choi, S. Kim, HuREX-A Framework of HRA Data Collection from Simulators in Nuclear Power Plants, Reliability Engineering & System Safety, vol. 194, 106235, http://dx.doi.org/10.1016/j.ress.2018.07.036, 2020.

[8] Cummings, M. L., Kevin Myers, and Stacey D. Scott., Modified Cooper Harper evaluation tool for unmanned vehicle displays, Proceedings of UVS Canada: Conference on Unmanned Vehicle Systems Canada, 2006.

[9] Coral, Melissa Patricia., Analyzing cognitive workload through eye-related measurements: A meta-analysis. Diss, Wright State University, 2016.

[10] Telford, C. W., and Norman Thompson., Some factors influencing voluntary and reflex eyelid responses, Journal of Experimental Psychology 16.4, 524, 1933.

[11] Endsley, Mica R., and Daniel J. Garland, eds., Situation awareness analysis and

measurement, CRC Press, 2000.

[12] Taylor, R.M., Situational awareness rating technique (SART): The development of a tool for aircrew systems design, in Situational awareness, Routledge, p. 111-128, 2017.