INL/CON-21-64996-Revision-0

Experimental Analysis of the Effects of Simulator Complexity on Human Performance

November 2021

Changing the World's Energy Future

Taewon Yang, Bumjun Park, Sungheon Lee, Jeong Hun Choi, Ronald Laurids Boring PhD, Jonghyun Kim, Jooyoung Park

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/CON-21-64996-Revision-0

Experimental Analysis of the Effects of Simulator Complexity on Human Performance

Taewon Yang, Bumjun Park, Sungheon Lee, Jeong Hun Choi, Ronald Laurids Boring PhD, Jonghyun Kim, Jooyoung Park

November 2021

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Experimental Analysis of the Effects of Simulator Complexity on Human Performance

Taewon Yang
Dept. Nuclear Engineering
Chosun University
Dong-gu, Gwangju, Republic of Korea
xodnjs0706@chosun.kr

Bumjun Park
Dept. Nuclear Engineering
Chosun University
Dong-gu, Gwangju, Republic of Korea
pbj1218@chosun.kr

Sungheon Lee
Dept. Nuclear Engineering
Chosun University
Dong-gu, Gwangju, Republic of Korea
leesh0867@chosun.kr

Jeong Hun Choi
Dept. Radiation Safety
Korea Hydro & Nuclear Power
Hongnong, Yeonggwang, Republic of Korea
choijh03@khnp.co.kr

Jooyoung Park
Dept. Human Factors and Reliability
Idaho National Laboratory
Idaho Falls, ID, USA
Jooyoung.Park@inl.gov

Ronald L. Boring
Dept. Human Factors and Reliability
Idaho National Laboratory
Idaho Falls, ID, USA
Ronald.Boring@inl.gov

Jonghyun Kim*
Dept. Nuclear Engineering
Chosun University
Dong-gu, Gwangju, Republic of Korea
jonghyun.kim@Chosun.ac.kr

***Abstract*—Human reliability analysis (HRA), which is used to predict accidents resulting from human errors, is an important factor in probabilistic safety assessments that comprehensively evaluate the safety of nuclear power plants (NPPs). This study analyzes how simulator complexity affects the performance of NPP operators and falls under Idaho National Laboratory's project to collect additional HRA data through the use of simulations. Experiments were conducted featuring two types of simulators and scenarios as independent variables. The data collected via these experiments were further evaluated using an analysis of variance (ANOVA) test and correlation analysis, resulting in the derivation of four human performance charts.**

Keywords—HRA, Human error, Human performance

I. INTRODUCTION

With the lack of human performance data being a major issue in conducting human reliability analysis (HRA) [1, 2], researchers have attempted to collect such data from a wide range of sources, including actual historical measurements, simulator studies, and expert opinion. Recent studies have chiefly focused on collecting the data by using full-scope simulators with actual operators. On the other hand, Idaho National Laboratory attempted to gather human performance data via its Simplified Human Error Experimental Program (SHEEP), which relies on a simplified simulator and student participants. Idaho National Laboratory has considered applying the SHEEP approach to simplified simulators such as Rancor Microworld and the Compact Nuclear Simulator (CNS) in order to complement—but not replace—full-scope studies and collect HRA data for estimating the nominal/basic human error probabilities required for HRA quantification.

This study compares the human performance data collected from benchmark experiments using two types of simplified simulators: a more simplified simulator (i.e., Rancor Microworld) and a less simplified one (i.e., CNS). By regarding the simulator type and scenario type as two independent variables, a randomized factorial experiment design was created. Four human performance measurements were selected: workload, situational awareness, time, and error. Several scenarios and related procedures were developed for simulation in both types of simulators, and the resulting data were then evaluated using an analysis of variance (ANOVA) test and a correlation analysis.

II. SHEEP FRAMEWORK

The SHEEP framework (depicted in Fig. 1) represents an ongoing effort to provide additional data to support and supplement full-scope studies. This framework is divided into three stages: (1) identification of collectible HRA items from a simplified simulator; (2) treatment of these HRA items, based on experimentation; and (3) integration of the data into a full-scope database for deployment in HRA methods.

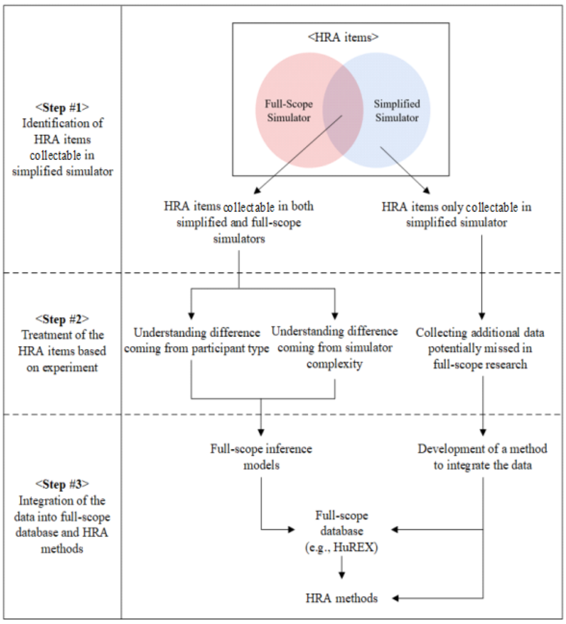

Fig. 1. SHEEP framework

In the first stage, all the collectible HRA data items are divided into two groups: (1) items collectible from both simplified and full-scope simulators, and (2) items only collectible from simplified simulators. The second stage suggests how experimentation can be used to treat the relevant HRA items classified in the first stage. For HRA items that are collectible from both full-scope and simplified simulators, this stage entails specifying the participant type (i.e., operator or student) and simulator complexity (i.e., simplified or full-scope). The design of the current study lays the groundwork for gathering the data needed to create full-scale inference models in the third stage. This final stage will aid in acquiring new HRA data that are missed by full-scope simulators because certain HRA items can only be obtained via a simplified simulator. The final stage integrates the experimental data from the preceding stage into a comprehensive(i.e., full scope) database applicable to HRA approaches.

This paper focuses on evaluating the HRA items obtained from both the simplified and full-scope simulations. An inference model is constructed for these items, based on the different participant types and simulator complexities. The detailed procedure for inferring full-scope data from simplified simulator data is shown in Fig. 2. Error data from operators and students using a more simplified simulator (i.e., Rancor Microworld [4]) or a less simplified one (i.e., CNS [3]) were collected via experimentation. Then, by devising a means of identifying the gaps between (1) operators and students, (2) the two simplified simulators, and (3) a simplified simulator and a full-scope simulator, the operator data for the full-scope environment are deduced from the simplified simulator's student data.

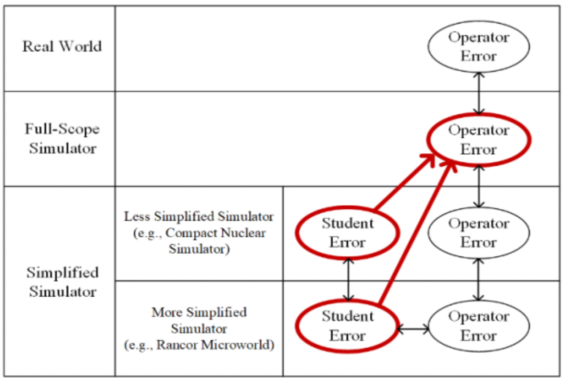

Fig. 2. Process of inferring full-scope data based on simplified simulator data

III. Experimimental Design

Previous studies [5, 6] collected human performance data for understanding the differences between operators and students when using Rancor Microworld (i.e., a more simplified simulator). The current study collected human performance data using CNS (i.e., a less simplified simulator), then compared those data with the data collected from Rancor Microworld, generating insights into the differences that arise due to simulator complexity. A randomized factorial experiment was used to compare the two simplified simulators in terms of human performance. The experimental design, which involved two independent variables (i.e., simulator type and scenario type), is outlined in Table I. Details on this experimental design are related in the following subsections.

TABLE I. Randomized Factorial Experiment Design

Type of scenario	Type of simulator	
	Rancor Microworld	*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 categories: a more simplified simulator (i.e., Rancor Microworld) and a less simplified one (i.e., CNS). Rancor Microworld is a simplified simulation environment that replicates the major characteristics of real nuclear power plant (NPP) operations [4]. It has been used to examine theoretical and practical designs related to process control, and its graphical user interface enables researchers to manipulate the process control systems. Rancor Microworld was built using thermo-hydraulics and with a gamified Rankine cycle, similar to that of small modular reactors. Fig. 3 illustrates Rancor Microworld's interface, which is comprised of three windows: the overview window, the piping and instrumentation diagram window, and the controls window. The overview window shows basic system information (e.g., the alarm panel). Its integrated design alerts operators whenever certain parameters fall outside their safe range. The piping and instrumentation diagram window show information such as pump operating status and the steam generator pressure if the valves are on and opened. Finally, the controls window applies to any controllable metric (e.g., by sliders and buttons). CNS (see Fig. 4) [3] is a representative simulator well-suited for this study. The Korean Atomic Energy Research Institute developed this simulator based on the Westinghouse 900 MWe, 3-Loop pressurized-water reactor, and it models the NPP's primary system, secondary system, and containment container. The power system is modeled, along with the Reactor Coolant System (RCS) for the primary system. The major differences between CNS and Rancor Microworld are shown in Table II.

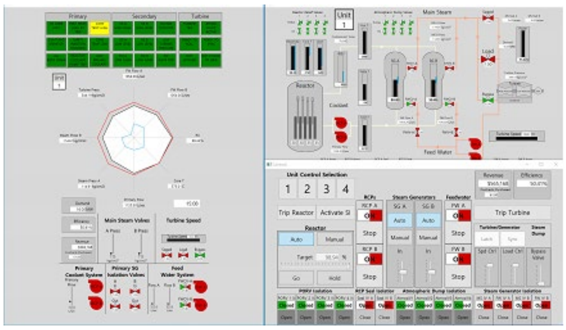

Fig. 3. Rancor Microworld interface screen

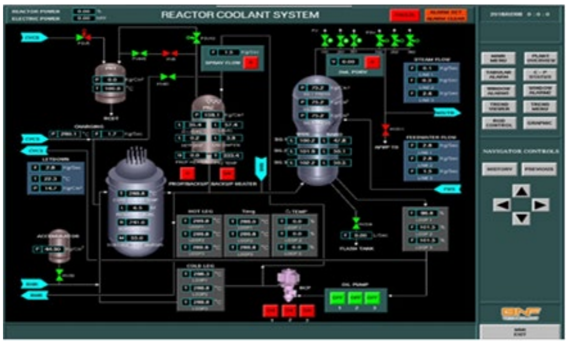

Fig. 4. CNS interface screen

TABLE II. COMPARISON OF THE CHARACTERISTICS OF RANCOR MICROWORLD 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) *Type of scenario*

There are two types of scenarios: non-events and events. Non-events include routine operations such as startup, shutdown, or full-power operation. In comparison to events, non-events place less responsibility and urgency on participants when performing tasks. Events, however, entail critical tasks that must be accomplished in a limited amount of time and can potentially affect the plant's future condition, either positively or negatively. Event scenarios include unusual events or emergencies.

B. *Experimental Scenarios*

For this experiment, scenarios and related procedures were developed for simulation using CNS. Compared to those considered in full-scope studies, these scenarios are rather simple. Table III lists the experimental scenarios, success criteria, and related procedures involved in the testing. Both non-events and events were simulated.

Each scenario ended when the participants completed a predetermined procedure or achieved a specified goal. When the reactor power reached a predetermined state (i.e., 0 or 50%), the non-event scenario ended. Once participants performed all the procedural steps or instructions, and parameters such as core temperature were maintainable at stable values, the event scenarios ended.

TABLE III. EXPERIMENT SCENARIOS AND PROCEDURE

Type of Scenario	Title	Description	Procedure	Success criteria
Non-event	Startup operation (2 to 50%)	Increase reactor power from 2 to 50% in fully automatic mode	OP-001 (Startup)	Reactor power = 50%
	No reactor trip during the operation	Shut down the reactor from 100 to 2% (hot-standby) in fully automatic mode	OP-002 (Shutdown)	Reactor power = 2%
Event	Steam generator tube rupture, with failure indicator for the steam generator level	For steam generator tube rupture, it is necessary to isolate the damaged steam generator, maintain safety functions, and reduce the RCS temperature.	EOP-E-3 (steam generator tube rupture)	Diagnosis of an initiating event or failure
	Isolation of damaged steam generator	Loss of feedwater pump requires isolating the damaged steam generator, maintaining safety functions, and reducing the RCS temperature.	EOP-E-2 (loss of feedwater)	Diagnosis of an initiating event or failure

C. *Human Performance Measurements*

For each scenario, four human performance measurements—workload, situational awareness, time, and error—were considered in the experiment. The following subsections detail each of these measurements.

1) *Time*

This human performance measurement represents the average time it takes to complete a step, instruction, or task. A procedure is a series of steps composed of instructions that generally include one or more tasks. Fig. 5 gives 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 in each scenario was calculated by dividing the number of errors by the total number of tasks. An error is defined as when an operator's task performance deviates from the intended actions. Errors include errors of omission and errors of commission. Errors of omission are caused by omitting a task, whereas errors of commission correspond to selection errors (e.g., selecting the incorrect control), errors of sequence (e.g., conducting tasks in incorrect order), time errors (e.g., acting 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 human reliability data extraction (HuREX) project [7]. Concerning the rules, if a participant commits an error but later corrects it, the experiment still counts it as an error. Regarding the analysis categories, the error types defined in the HuREX framework are used to categorize the errors counted in each scenario. The HuREX framework is used to count the number of errors, as seen in Fig. 6.

Event Class	Scenario	Type of Error	Student #1 Number of errors	Student #1 Total	Student #2 Number of errors	Student #2 Total	Student #3 Number of errors	Student #3 Total	Student #4 Number of errors	Student #4 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 using the HuRex framework

3) *Workload*

This study applies the modified Cooper-Harper (MCH) rating scale [8] to estimate workload. This scale was developed by the aviation industry to measure the physical and psychological workloads of operators. It is also used to suggest design recommendations. After each scenario, responses to the questionnaire shown in Fig. 7 are used to evaluate workloads.

An alternative approach to estimating workload is to use an eye-tracker. According to certain studies [9, 10], there is a correlation between blink rate and cognitive effort. However, this relationship was not taken into account in this study.

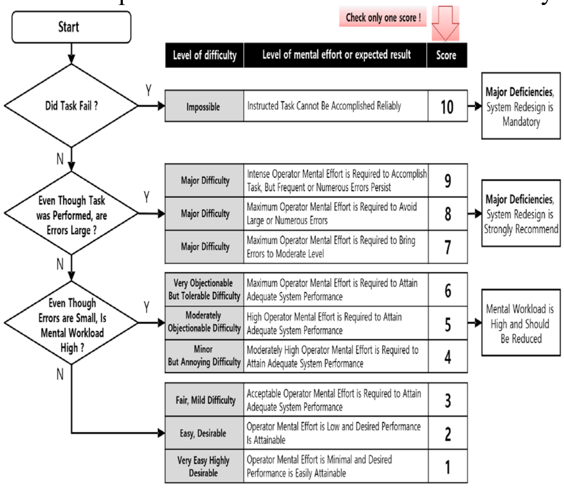

Fig. 7. Questionnaire used for the MCH rating scale

4) *Situational awareness*

Situational awareness indicates perception of elements in an environment within a specific volume of time and space and involves comprehending the meaning of the situation and predicting the status of the elements in the near future [11]. This study employed the Situational Awareness Rating Technique (SART) [12] to estimate subjects' situational awareness. The questionnaire used for the SART rating scale is shown in Fig. 8.

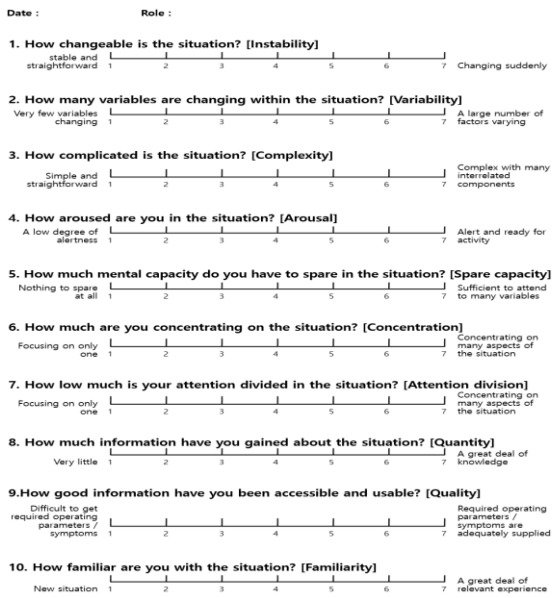

Fig. 8. Questionnaire used for the SART rating scale

D. *Subjects*

A total of 36 participants were involved in this project: 20 in the Rancor Microworld experiments and 16 in the CNS experiments. These participants were either licensed operators employed at Korean NPPs or experts with extensive experience in NPP operations.

E. *Facility*

Rancor Microworld and CNS were installed on a laptop dedicated solely to the experiments, which were performable without using a desk, chair, or power source. Subjects could also use the laptop's touch screen to control the simulators.

F. *Data Acquisition*

In this study, the eye-tracker and aforementioned questionnaires accounted for the bulk of the data collection activities (without considering the relationship between blink rate and cognitive workload). These data acquisition methods, the items collectible therefrom, and the resulting human performance measurements are summarized in Table IV. The items collectible using each method were directly linked to human performance data. Additional data can be derived to aid in comprehending the study results and constructing alternate strategies for identifying further notable outcomes.

TABLE IV. SUMMARY OF DATA ACQUISITION METHODS, ITEMS COLLECTIBLE THEREFROM, AND HUMAN PERFORMANCE MEASUREMENTS

Method	All items collected	Human performance
Questionnaires	General information on 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 blink data	Time Error Workload

G. *Training*

The purpose of the experiment, a description of the simulators and their systems, potential scenarios, questionnaires, and practice sessions were all included in the training material prepared for each participant. Each participant received 2 hours of training prior to the experiment.

H. Data Analysis

The data from the experiments were analyzed in three different ways. The randomized factorial experiment design was the first step in a statistical analysis. Furthermore, an ANOVA test and a correlation analysis were conducted to identify significant relationships between items collected for each independent variable.

IV. Result

This section discusses the analytical findings. The differences in the human performance data can be traced back to the two independent variables (i.e., simulator type and scenario type), as well as the correlations in the human performance data for Rancor Microworld and CNS. These differences were investigated using two statistical analysis methods: ANOVA testing and a correlation analysis.

A. Results of the ANOVA Test

The amount of variability between the group means (in the context of variation within groups) was determined by conducting an ANOVA test on each human performance measurement, revealing whether the mean differences were statistically significant. The ANOVA test results are summarized in Table V.

Several human performance measurements exhibited significant differences based on simulator/scenario type. Furthermore, except for the MCH scores, all the measurements, regardless of scenario type, were statistically different. All the measurements for non-event scenarios revealed statistically significant differences, as did all the measurements for the event scenarios, save for the SART scores. The following subsections explore these findings in greater detail.

TABLE V. 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	*Task completion time*	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 proved insignificant when all the data were analyzed via the ANOVA test but were significant when considering the event and non-event scenarios separately. When using Rancor Microworld, the average MCH score for non-event scenarios (3.20) indicated a higher workload than that for event scenarios (3.03). On the other hand, when CNS was used, the opposite was observed: the average MCH score for non-event scenarios (2.25) indicated a lower workload than that for event scenarios (4.00). Fig. 9 shows the overall trends in workload.

Fig. 9. Overall workload trends

2) Situational awareness

For event scenarios, the SART values for each simulator type were insignificant. Even so, there were statistically significant differences in terms of scenario type. As the simulator complexity increased (switching from Rancor Microworld to CNS), so did the SART values measured for the non-event scenarios and the two scenario types combined. Fig. 10 shows the overall situational awareness trends.

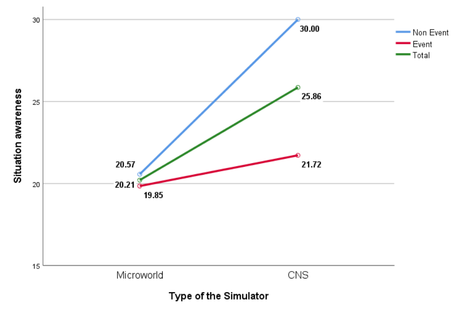

Fig. 10. Overall situational awareness trends

3) Time

For event scenarios, non-event scenarios, and the two types of scenarios combined, the time to complete a task reflected statistically significant values in regard to simulator type. As the simulator's complexity increased (switching from Rancor Microworld to CNS), higher values occurred. The overall average time trends are seen in Fig. 11.

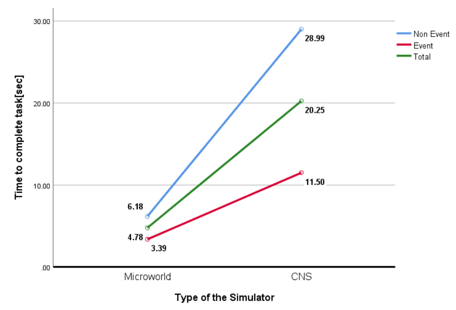

Fig. 11. Overall average time trends

4) Error rate

For event scenarios, non-event scenarios, and the two types of scenarios combined, the error rate reflected statistically significant values in regard to simulator type. As the simulator's complexity increased (switching from Rancor Microworld to CNS), higher values occurred. The overall error rate trends are depicted in Fig. 12.

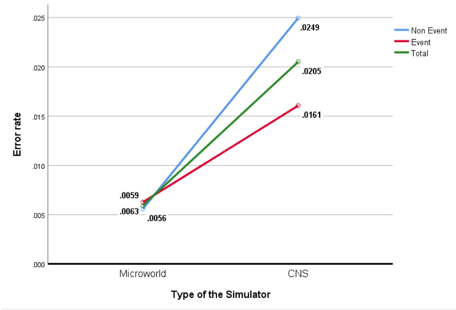

Fig. 12. Overall error rate value trends

B. *Results of the Correlation Analysis*

Correlation analysis was employed to explore how the human performance measurements corresponded to one another in light of the different simulator complexities. Such analysis can reveal the relationships between two independent variables or prove them to be truly independent. The direction and intensity of a linear relationship are measured by the correlation coefficient, r. Correlations between human performance measurements can be discovered via the Pearson product-moment correlation coefficient, which indicates (1) whether two continuous variables share a statistically significant linear relationship, (2) the strength of any linear relationship (i.e., how closely a plot of the relationship resembles a perfectly straight line), and (3) the direction of a linear relationship (i.e., increasing or decreasing). Generally, a correlation coefficient of $r = -1$ means a completely negative correlation, whereas a value of $r = 1$ means a completely positive correlation. In addition, in regard to correlation degree, values of ±0.70–±1 normally indicate strong correlations, values of ±0.40–±0.69 indicate moderate correlations, and anything under ±0.39 indicates a low correlation [13]. The correlation analysis results for all data from Rancor Microworld and CNS are shown in Tables VI–VIII.

TABLE VI. 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**	0.421**	1

TABLE VII. 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	-0.070	1

TABLE VIII. 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

In Tables VI–VIII, the symbols * and ** show the statistical difference considered within a confidence level of 95% (i.e., $p < 0.05$) and 99% (i.e., $p < 0.01$), respectively, as a result of correlation analysis of the independent variable. Table VI shows the results of the correlation analysis data for all the participants combined. In Table VI, situational awareness correlates with all the other human performance measures, apart from workload and error. The correlations between situational awareness and the other human performance measures were all moderate (i.e., within the significance level), except as regards the error rate, whose correlation with situational awareness was weak. On the other hand, time reflected a moderate correlation with the error rate, but a weak correlation with workload. When using Rancor Microworld, only the correlation between situational awareness and workload was weak and no correlations of any kind were found between the remaining human performance measurements (see Table VII). However, when using CNS, four sets of correlations were observed (see Table VIII). Time had a moderate correlation with both workload and error rate and a weak correlation with situation awareness. Also, workload had a moderate correlation with situational awareness, as shown in Tables VI and VII.

V. CONCLUSION

This study attempts to identify differences in human performance between using Rancor Microworld and using CNS, based on benchmark studies and employing the SHEEP framework. Using two independent variables (i.e., simulator type and scenario type), a randomized factorial experiment design was developed. Four human performance indicators were selected: workload, situational awareness, time, and error. Then, using the two simulators, various scenarios and related procedures were developed and simulated. Finally, two statistical analysis methods were used to analyze the data collected from the experiments: an ANOVA test and correlation analysis.

When comparing operator performance in Microworld and CNS, no significant difference in terms of workload was discovered. However, as the simulator complexity increased when switching from Rancor Microworld to CNS, the situational awareness, average time to complete a task, and error rate all reflected higher values. The correlation analysis results revealed workload and situational awareness to be statistically significant. Similarly, error rate and situational awareness were found to have a statistically significant effect on operator performance. In addition, the average time to complete a task was correlated to workload, situational awareness, and error rate.

The results of this study, which reveal that operator performance differs based on simulator complexity, are intended to foster development of a future study for inferring operator performance in full-scope simulator environments. In other words, these results will aid future research for collecting data in order to definitively understand the various correlation between participant type (i.e., operators vs. students) and simulator complexity (i.e., simplified simulators vs. full-scope simulators).

VI. ACKNOWLEDGMENTS

This study was 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.

REFERENCES

[1] J. Park, D. Lee, W. Jung, J. Kim, “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] A.D. Swain and H. E. Guttmann, “Handbook of human-reliability analysis with emphasis on nuclear power plant applications, Final report”, Sandia National Labs, 1983.

[3] K.-C. Kwon, J.-C. Park, C.-H. Jung, J.-S. Lee, J.-Y. Kim, “Compact nuclear simulator and its upgrade plan”, 1997.

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

[5] J. Park, T.A. Ulrich, R.L. Boring, S. Lee, J. Kim, “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] J. Kim, J. Park, R.L. Boring, T.A. Ulrich, S. Lee, “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] W. Jung, 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, 2020.

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

[9] M.P. Coral, “Analyzing cognitive workload through eye-related measurements: A meta-analysis”, Wright State University, 2016.

[10] C.W. Telford, and N. Thompson., “Some factors influencing voluntary and reflex eyelid responses”, Journal of Experimental Psychology, 1933.

[11] M.R. Endsley, and D. J. Garland “Situation awareness analysis and measurement”, CRC Press, 2000.

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

[13] P. Schober, C. Boer, L.A. Schwarte, “Correlation Coefficients: Appropriate Use and Interpretation”, Anesthesia & Analgesia, vol. 126, p: 1763-1768, 2018