INL/CON-22-70270-Revision-0

INLs Human Reliability Analysis Data Collection

November 2022

Jooyoung Park

Changing the World's Energy Future

Idaho National Laboratory

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

INL/CON-22-70270-Revision-0

INLs Human Reliability Analysis Data Collection

Jooyoung Park

November 2022

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

INL's Human Reliability Analysis Data Collection Based on the SHEEP Framework

Jooyoung Park

Idaho National Laboratory

1. Introduction
2. The SHEEP Framework
3. HuREX Analysis
4. Human Performance Analysis
5. TACOM Analysis
6. Learning Effect Analysis
7. Future Work

1. Introduction

1. Background

Efforts to Collect HRA Data to Date

- A lack of data has been identified as one of the challenges in human reliability analysis (HRA).
- The most recent studies are concentrating on collecting the data from full-scope studies using full-scope simulator and actual operator.
  - U.S.NRC (SACADA) / KAERI (HuREX)
    - *SACADA: Scenario, Authoring, Characterization, and Debriefing Application*
    - *HuREX: Human Reliability data EXtraction*
  - Good to collect high fidelity simulator data instead of historical operational data

Challenges to Perform Full-Scope Studies

- Difficult to get actual operators for continuously collecting a variety of data due to the high cost
- Utilities' cooperation and data release are relatively limited to few organizations.

1. Background

INL's Approach to HRA Data Collection

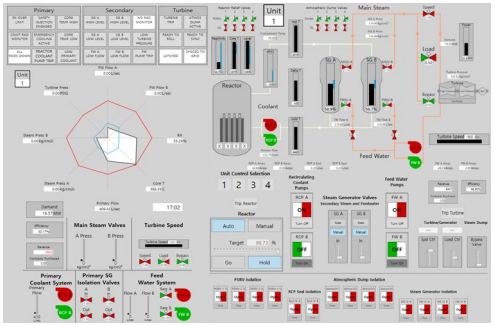
- To collect HRA data through the Simplified Human Error Experimental Program (SHEEP)
  - To use simplified simulators and students as a complement – not a replacement – for full-scope studies.
  - To provide the data to support full-scope data collection efforts such as HuREX and SACADA

<Idaho National Laboratory>

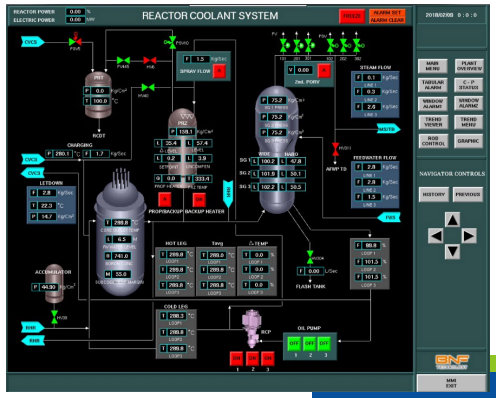
<Chosun University>

<KAERI>

Collecting and analyzing data from simplified simulators, students and operators



<Rancor Microworld>

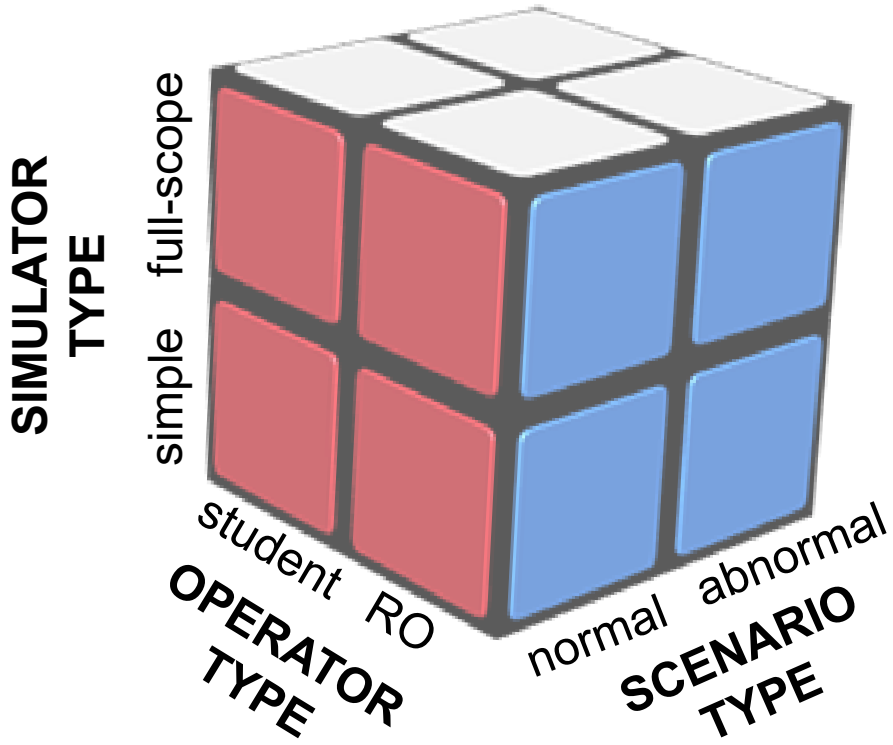


<Compact Nuclear Simulator (CNS)>

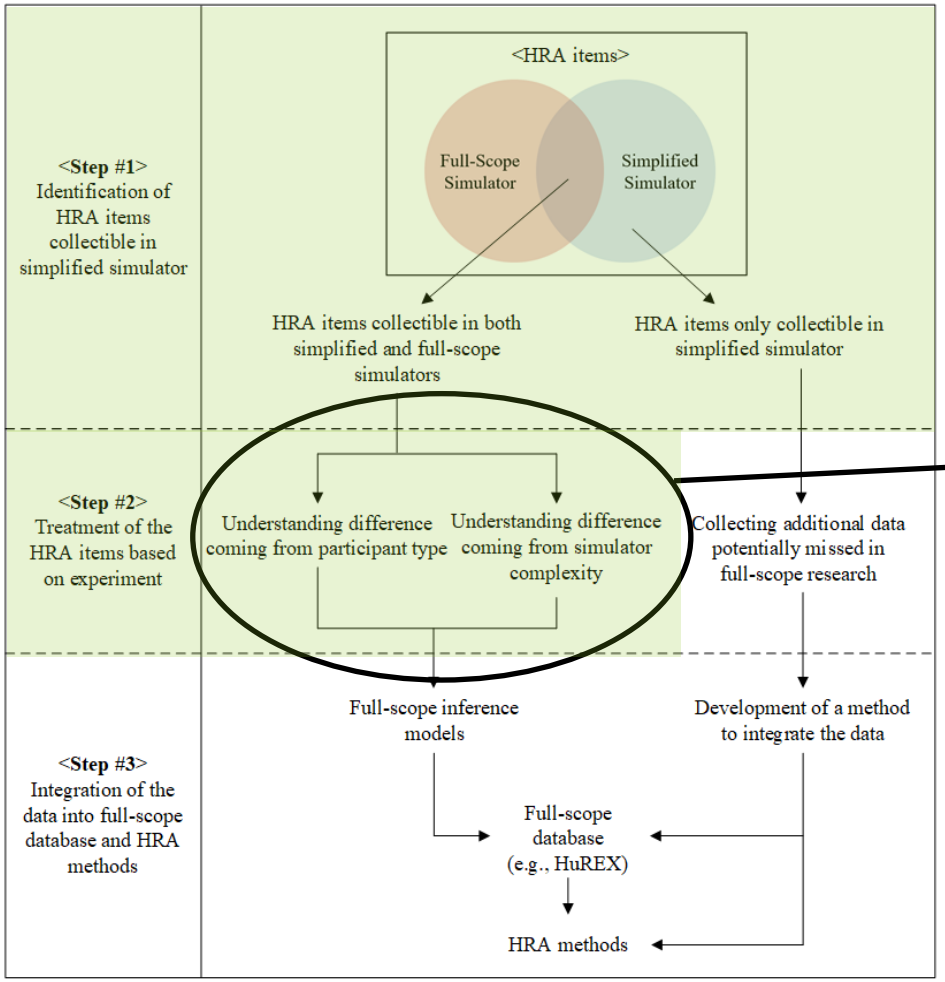
1. Background

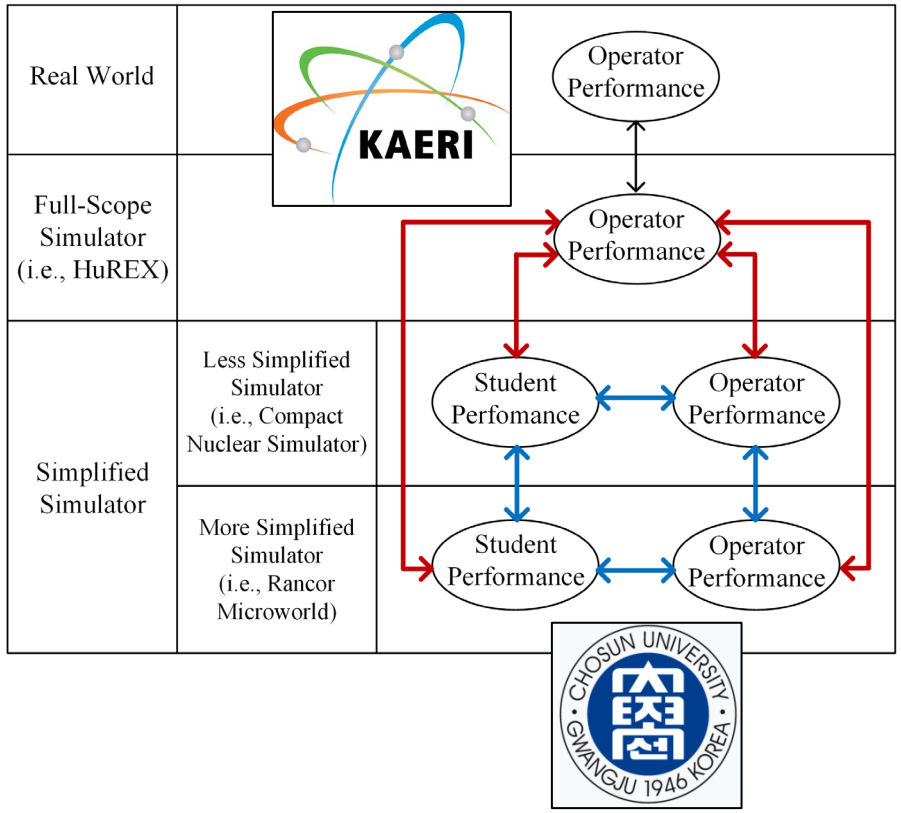
Basic Design

- Operator Type (Student vs. Reactor Operator)
- Simulator Type (Simplified vs. Less Simplified vs. full-scope)
- Scenario Type (Normal vs. Abnormal)



2. The SHEEP Framework





Park, J., Boring, R. L., Ulrich, T. A., Lew, R., Lee, S., Park, B., and Kim, J. A framework to collect human reliability analysis data for nuclear power plants using a simplified simulator and student operators, *Reliability Engineering and System Safety*, 108326, (2022)

2. The SHEEP Framework

▶ Step #1: Identification of HRA items collectible in simplified simulators

- Items collectible in both simplified and full-scope simulators
  - 22 HuREX task types

Table 1
Task types collectible in full-scope simulators and collectability of those task types in the Rancor Microworld.

Cognitive activity	Task types collectible in a full-scope simulator (HuREX)	Collectability using the rancor microworld
Information gathering and reporting (IG)	IG-alarm	Collectible
	IG-indicator	Collectible
	IG-synthesis	Uncollectible
	IG-value	Collectible
	IG-comparison	Collectible
	IG-graph	Uncollectible
	IG-abnormality	Uncollectible
	IG-trend	Collectible
Response planning and instruction (RP)	RP-entry	Collectible
	RP-procedure	Collectible
	RP-step	Collectible
	RP-information	Uncollectible
	RP-manipulation	Uncollectible
	RP-notification	Uncollectible
Situation interpreting (SI)	SI-diagnosis	Uncollectible
	SI-identification	Uncollectible
	SI-prediction	Uncollectible
Execution (EX)	EX-discrete	Collectible
	EX-continuous	Collectible
	EX-dynamic	Collectible
	EX-notification	Uncollectible
Other (OT)	OT-manipulation	Collectible

- Items only collectible in simplified simulators
  - 88 generic data items collectible in simulator studies

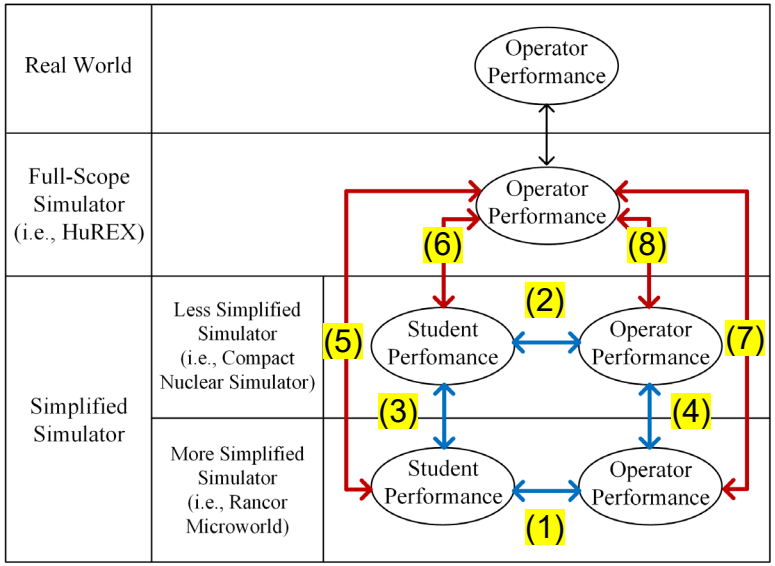
Table 2
HRA items only collectible in simplified simulators [40].

Category	Subcategory	HRA Item	Representatively measurable instance
HSI	Ergonomics	The existence of barriers	- Failsafe designs - Administrative control - Physical guards or stops - Logical/mechanical interlocks
		The existence of buffers	- Redundant structures or processes - Features to accept time delays - Design for reversible, confirmatory, or staged actions
		The provision of memory aids	- Memory aid from human-machine interface
	Panel design	The conformity of standards, conventions, and nomenclature	- Consistent use of measurement units, information coding, or device configuration - Standard nomenclature defined from NPP administrative procedures
		The availability of indications (clarity of cues/indicators)	- Not specified from existing references
		The availability of controls (devices)	- Not specified from existing references
	Status indication	The existence of wrong or inadequate information	- Not specified from existing references
		The appropriateness of task feedbacks	- Clear, prompt, or precise feedback information
		The provision of clear decision criteria	- Clear decision criteria from the human-machine interface Ambiguous decision criteria in a procedure

※ Park, J., et al.: A guideline to collect HRA data in the simulator of nuclear power plants. KAERI/TR-5206/2013 (2013)

2. The SHEEP Framework

▶ Step #2: Treatment of the HRA items based on experiment



No.	The Relationship	Method	Data Analysis			
			HuREX Analysis	Human Performance Analysis	TACOM Analysis	Learning Effect Analysis
(1)	**Student** vs. **Operator** / Rancor	**Experiment**	**Done**	**Done**	**N/A**	**Done**
(2)	**Student** vs. **Operator** / CNS	**Experiment**	**Done**	**Done**	**N/A**	**N/A**
(3)	**CNS** vs. **Rancor** / Student	**Experiment**	**Done**	**Done**	**N/A**	**N/A**
(4)	**CNS** vs. **Rancor** / Operator	**Experiment**	**Done**	**Done**	**N/A**	**N/A**
(5)	**Student + Rancor** vs. **Operator + Full-Scope**	**Comparison with HuREX Data**	**Done**	**N/A**	**Done**	**N/A**
(6)	**Student + CNS** vs. **Operator + Full-Scope**	**Comparison with HuREX Data**	**Done**	**N/A**	**Not Started**	**N/A**
(7)	**Rancor** vs. **Full-Scope** / Operator	**Comparison with HuREX Data**	**Done**	**N/A**	**Done**	**N/A**
(8)	**CNS** vs. **Full-Scope** / Operator	**Comparison with HuREX Data**	**Done**	**N/A**	**Not Started**	**N/A**

2. The SHEEP Framework

▶ Step #2: Treatment of the HRA items based on experiment

- Experimental Design
  - Two independent variables, i.e., participant type and event class

<The Randomized Factorial Experiment with Rancor Microworld>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			· Fully auto start-up (0% to 100%) · Shutdown (100% to 0%) · Start-up with manual rod control (0% to 100%) · Start-up with manual feedwater flow control (0% to 100%)
Event			· Failure of a reactor coolant pump under full-power operation · Failure of a control rod under full-power operation · Failure of a feedwater pump under full-power operation · Abnormal turbine trip under full-power operation · Steam generator tube rupture with an indicator failure · Loss of feedwater pump

<The Randomized Factorial Experiment with CNS>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			· Fully auto startup (0% to 100%) · Shutdown (100% to 0%)
Event			· Steam generator tube rupture with an indicator failure · Loss of feed-water pump

2. The SHEEP Framework

- **Step #2: Treatment of the HRA items based on experiment**
  - Human Performance

Human Performance Categories	Human Performance Measurements
Workload	Modified Cooper-Harper (MCH)
Situation awareness	Situation Awareness Rating Technique (SART)
Error	Error rate
Time to completion	Average time to complete a step
	Average time to complete an instruction
	Average time to complete a task
Eye movements	Eye fixation count per task
	Eye fixation duration per task
	Blink rate (i.e., blink count per task)
	Heatmap over area of interest (AOI)
Number of manipulations	Number of manipulations per task
	Number of manipulations per scenario completion time

2. The SHEEP Framework

- **Step #2: Treatment of the HRA items based on experiment**
  - Participants
    - Students
      - Undergraduate senior students and master students at the department of nuclear engineering in Chosun University
      - They took courses such as "Introduction to Nuclear Engineering," "Reactor Theory," "Reactor Control", and "Simulator Operation."
    - Operators
      - Licensed operators for Westinghouse type
      - Working at Hanbit Nuclear Site in Korea

	Student	Operator
Microworld	20	20
CNS	16	16

3. HuREX Analysis

Cognitive Activity	Task Type	HUREX Study			SHEEP Study (Using the Rancor Microworld)					
					Student			Operator		
		Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC
Information Gathering and Reporting	IG-alarm	1,387	-	1	701	-	-	714	-	-
	IG-indicator	9,572	-	19	1,370	-	6	1,417	-	-
	IG-synthesis	598	-	2	-	-	-	-	-	-
	IG-value	334	-	-	146	-	-	144	-	-
	IG-comparison	6,930	-	1	1,056	-	-	1,082	-	-
	IG-graph	256	-	-	-	-	-	-	-	-
	IG-abnormality	1,594	-	-	-	-	-	-	-	-
	IG-trend	2,121	-	4	317	-	-	310	-	-
Response Planning and Instruction	RP-entry	624 (analog)	2 (analog)	-	1,650	-	-	1,653	-	-
	RP-procedure	253 (analog)	1 (analog)	-	132	-	6	135	-	3
	RP-step	71 (analog)	4 (analog)	-	993	2	7	982	9	6
	RP-information	8,840	22	9	-	-	-	-	-	-
	RP-manipulation	1,967	24	10	-	-	-	-	-	-
	RP-notification	387	18	-	-	-	-	-	-	-
Situation Interpreting	SI-diagnosis	12	-	-	-	-	-	-	-	-
	SI-identification	197	-	1	-	-	-	-	-	-
	SI-prediction	4	-	-	-	-	-	-	-	-
Execution	EX-discrete	2,762	34	3	1,342	2	-	1,323	2	-
	EX-continuous	87	4	-	556	-	23	565	5	12
	EX-dynamic	556	20	9	44	-	22	43	-	15
	EX-notification	366	7	-	-	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	10	-	-	2
Total		38,918	136	59	8,307	4	74	8,368	16	38

3. HuREX Analysis

Cognitive Activity	Task Type	HUREX Study			SHEEP Study (Using the CNS)					
					Student			Operator		
		Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC
Information Gathering and Reporting	IG-alarm	1,387	-	1	182	-	-	182	1	-
	IG-indicator	9,572	-	19	1,754	3	19	1,786	-	10
	IG-synthesis	598	-	2	-	-	-	-	-	-
	IG-value	334	-	-	-	-	-	-	-	-
	IG-comparison	6,930	-	1	1,216	-	-	1,257	-	-
	IG-graph	256	-	-	65	3	-	70	1	-
	IG-abnormality	1,594	-	-	0	-	-	0	-	-
	IG-trend	2,121	-	4	62	-	-	70	-	-
Response Planning and Instruction	RP-entry	624 (analog)	2 (analog)	-	1,394	-	-	1,437	-	-
	RP-procedure	253 (analog)	1 (analog)	-	27	1	1	30	-	-
	RP-step	71 (analog)	4 (analog)	-	2,958	14	14	3,038	3	3
	RP-information	8,840	22	9	-	-	-	-	-	-
	RP-manipulation	1,967	24	10	-	-	-	-	-	-
	RP-notification	387	18	-	-	-	-	-	-	-
Situation Interpreting	SI-diagnosis	12	-	-	20		1	17	-	-
	SI-identification	197	-	1	30	3	6	30	-	-
	SI-prediction	4	-	-	-	-	-	-	-	-
Execution	EX-discrete	2,762	34	3	963	2	6	1,041	8	-
	EX-continuous	87	4	-	259	-	3	274	-	-
	EX-dynamic	556	20	9	118	3	2	128	1	-
	EX-notification	366	7	-	-	-	-	-	-	-
Other	OT-manipulation	-	-	-	9,048	-	4	9,360	-	1
Total		38,918	136	59	9,048	23	57	9,360	12	17

3. HuREX Analysis

Cognitive Activity	Task Type	SHEEP Study (Using the Rancor Microworld)						SHEEP Study (Using the CNS)					
		Student			Operator			Student			Operator		
		Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC
Information Gathering and Reporting	IG-alarm	701	-	-	714	-	-	182	-	-	182	1	-
	IG-indicator	1,370	-	6	1,417	-	-	1,754	3	19	1,786	-	10
	IG-synthesis	-	-	-	-	-	-	-	-	-	-	-	-
	IG-value	146	-	-	144	-	-	-	-	-	-	-	-
	IG-comparison	1,056	-	-	1,082	-	-	1,216	-	-	1,257	-	-
	IG-graph	-	-	-	-	-	-	65	3	-	70	1	-
	IG-abnormality	-	-	-	-	-	-	0	-	-	0	-	-
	IG-trend	317	-	-	310	-	-	62	-	-	70	-	-
Response Planning and Instruction	RP-entry	1,650	-	-	1,653	-	-	1,394	-	-	1,437	-	-
	RP-procedure	132	-	6	135	-	3	27	1	1	30	-	-
	RP-step	993	2	7	982	9	6	2,958	14	14	3,038	3	3
	RP-information	-	-	-	-	-	-	-	-	-	-	-	-
	RP-manipulation	-	-	-	-	-	-	-	-	-	-	-	-
	RP-notification	-	-	-	-	-	-	-	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	-	-	-	20		1	17	-	-
	SI-identification	-	-	-	-	-	-	30	3	6	30	-	-
	SI-prediction	-	-	-	-	-	-	-	-	-	-	-	-
Execution	EX-discrete	1,342	2	-	1,323	2	-	963	2	6	1,041	8	-
	EX-continuous	556	-	23	565	5	12	259	-	3	274	-	-
	EX-dynamic	44	-	22	43	-	15	118	3	2	128	1	-
	EX-notification	-	-	-	-	-	-	-	-	-	-	-	-
Other	OT-manipulation	-	-	10	-	-	2	9,048	-	4	9,360	-	1
Total		8,307	4	74	8,368	16	38	9,048	23	57	9,360	12	17

3. HuREX Analysis

Cognitive Activity	Task Type	HUREX Study		SHEEP Study (Using the Rancor Microworld)			
		HEP (EOO)	HEP (EOC)	HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator
Information Gathering and Reporting	IG-alarm	-	3.610e-4	-	-	-	-
	IG-indicator	-	9.940e-4	-	4.380e-03	-	-
	IG-synthesis	-	1.680e-3	-	-	-	-
	IG-value	-	-	-	-	-	-
	IG-comparison	-	7.220e-5	-	-	-	-
	IG-graph	-	-	-	-	-	-
	IG-abnormality	-	-	-	-	-	-
	IG-trend	-	9.450e-4	-	-	-	-
Response Planning and Instruction	RP-entry	3.205e-3 (analog)	-	-	-	-	-
	RP-procedure	3.953e-3 (analog)	-	-	4.545e-02	-	2.222e-02
	RP-step	5.634e-2 (analog)	-	2.014e-03	7.049e-03	9.165e-03	6.110e-03
	RP-information	2.490e-3	5.110e-4	-	-	-	-
	RP-manipulation	1.230e-2	2.590e-3	-	-	-	-
	RP-notification	4.650e-2	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	-	-	-
	SI-identification	-	2.550e-3	-	-	-	-
	SI-prediction	-	-	-	-	-	-
Execution	EX-discrete	1.230e-2	5.500e-4	1.490e-03	-	1.512e-03	-
	EX-continuous	4.600e-2	-	-	4.137e-02	8.850e-03	2.124e-02
	EX-dynamic	3.660e-2	8.540e-3	-	5.000e-01	-	3.488e-01
	EX-notification	1.910e-2	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	-

3. HuREX Analysis

Cognitive Activity	Task Type	HUREX Study		SHEEP Study (Using the CNS)			
		HEP (EOO)	HEP (EOC)	HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator
Information Gathering and Reporting	IG-alarm	-	3.610e-4	-	-	5.495E-03	-
	IG-indicator	-	9.940e-4	1.710E-03	1.083E-02	-	5.599E-03
	IG-synthesis	-	1.680e-3	-	-	-	-
	IG-value	-	-	-	-	-	-
	IG-comparison	-	7.220e-5	-	-	-	-
	IG-graph	-	-	4.615E-02	-	1.429E-02	-
	IG-abnormality	-	-	-	-	-	-
	IG-trend	-	9.450e-4	-	-	-	-
Response Planning and Instruction	RP-entry	3.205e-3 (analog)	-	-	-	-	-
	RP-procedure	3.953e-3 (analog)	-	3.704E-02	3.704E-02	-	-
	RP-step	5.634e-2 (analog)	-	4.733E-03	4.733E-03	9.875E-04	9.875E-04
	RP-information	2.490e-3	5.110e-4	-	-	-	-
	RP-manipulation	1.230e-2	2.590e-3	-	-	-	-
	RP-notification	4.650e-2	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	5.000E-02	-	-
	SI-identification	-	2.550e-3	1.000E-01	2.000E-01	-	-
	SI-prediction	-	-	-	-	-	-
Execution	EX-discrete	1.230e-2	5.500e-4	2.077E-03	6.231E-03	7.685E-03	-
	EX-continuous	4.600e-2	-		1.158E-02		-
	EX-dynamic	3.660e-2	8.540e-3	2.542E-02	1.695E-02	7.813E-03	-
	EX-notification	1.910e-2	-	-	-	-	-
Other	OT-manipulation	-	-	-	4.421E-04	-	1.068E-04

3. HuREX Analysis

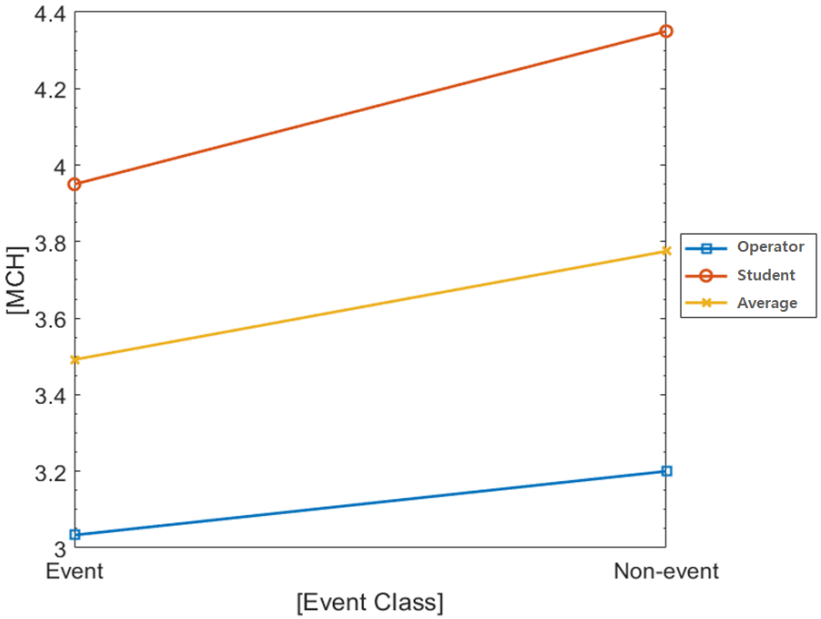
Cognitive Activity	Task Type	SHEEP Study (Using the Rancor Microworld)				SHEEP Study (Using the CNS)			
		HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator	HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator
Information Gathering and Reporting	IG-alarm	-	-	-	-	-	-	5.495E-03	-
	IG-indicator	-	4.380e-03	-	-	1.710E-03	1.083E-02	-	5.599E-03
	IG-synthesis	-	-	-	-	-	-	-	-
	IG-value	-	-	-	-	-	-	-	-
	IG-comparison	-	-	-	-	-	-	-	-
	IG-graph	-	-	-	-	4.615E-02	-	1.429E-02	-
	IG-abnormality	-	-	-	-	-	-	-	-
	IG-trend	-	-	-	-	-	-	-	-
Response Planning and Instruction	RP-entry	-	-	-	-	-	-	-	-
	RP-procedure	-	4.545e-02	-	2.222e-02	3.704E-02	3.704E-02	-	-
	RP-step	2.014e-03	7.049e-03	9.165e-03	6.110e-03	4.733E-03	4.733E-03	9.875E-04	9.875E-04
	RP-information	-	-	-	-	-	-	-	-
	RP-manipulation	-	-	-	-	-	-	-	-
	RP-notification	-	-	-	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	-	-	5.000E-02	-	-
	SI-identification	-	-	-	-	1.000E-01	2.000E-01	-	-
	SI-prediction	-	-	-	-	-	-	-	-
Execution	EX-discrete	1.490e-03	-	1.512e-03	-	2.077E-03	6.231E-03	7.685E-03	-
	EX-continuous	-	4.137e-02	8.850e-03	2.124e-02		1.158E-02		-
	EX-dynamic	-	5.000e-01	-	3.488e-01	2.542E-02	1.695E-02	7.813E-03	-
	EX-notification	-	-	-	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	4.421E-04	-	1.068E-04

4. Human Performance Analysis

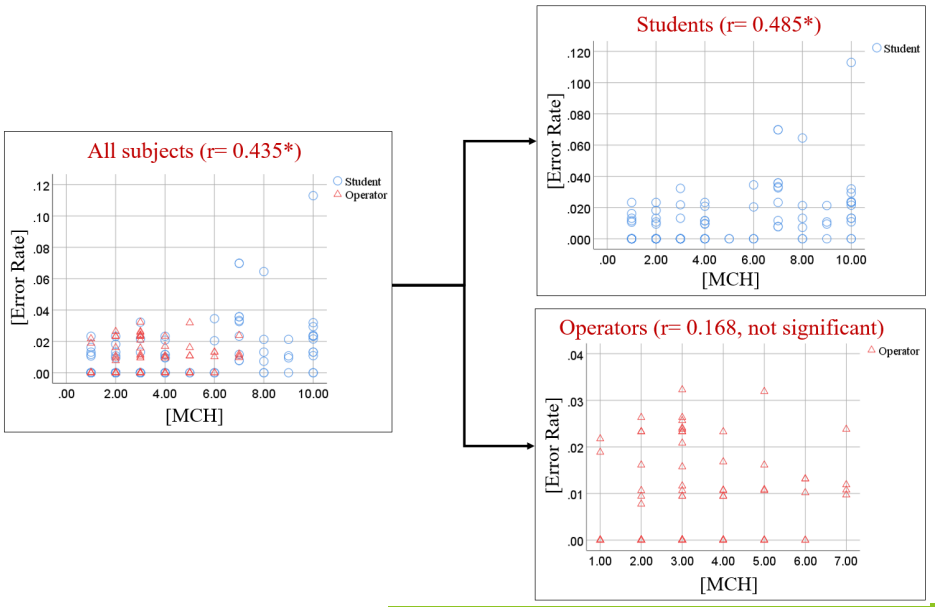
Method

- ANOVA Test
  - To identify statistical differences on human performance measurements depending on participant type and event class
- Correlation Analysis
  - To identify the relationship between human performance measurements

<Workload trend>



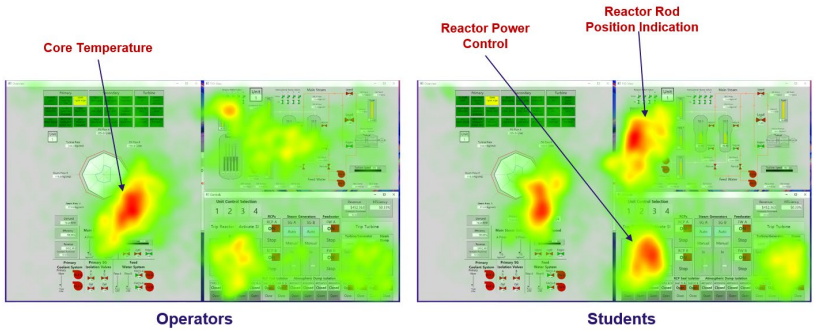
<Workload – Error rate>



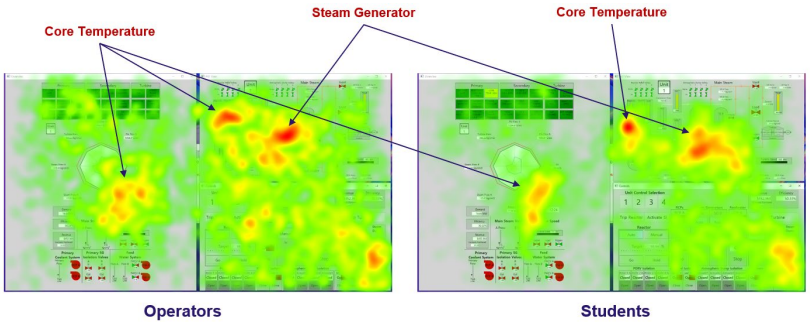
4. Human Performance Analysis

Method

- Eye Tracking Data Analysis
  - The operators are more likely to concentrate on major parameters necessary to the context of a given scenario as well as monitor overall interface.
  - Because the students are unfamiliar with the basic structure of the simulator and its interface, they may continually seek out options in the control window, as well as changes implemented due to a particular manipulation.



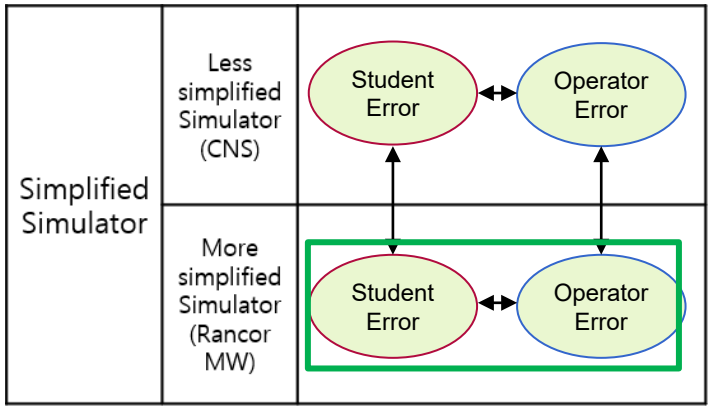
Non-event scenarios

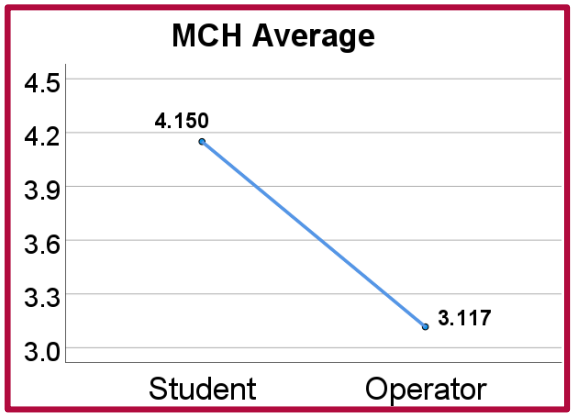


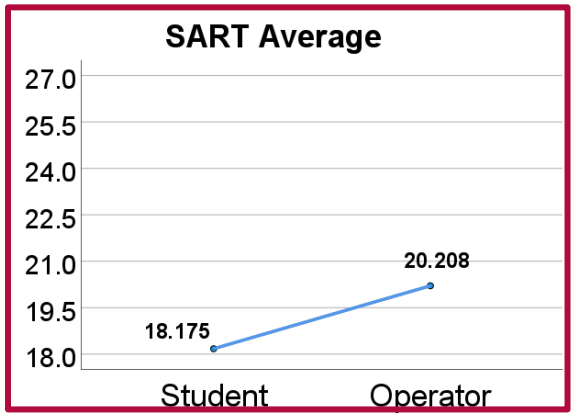
Event scenarios

4. Human Performance Analysis

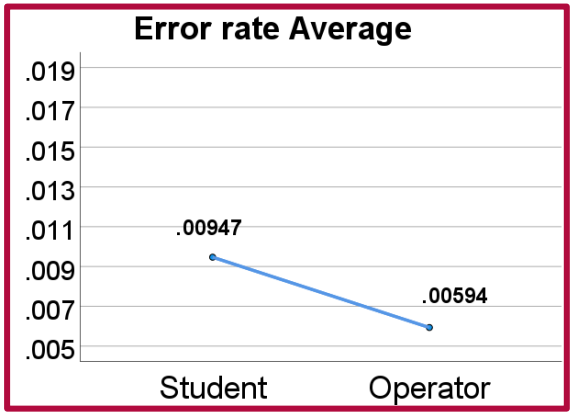
▶ Rancor MW, Between Subjects (2020)

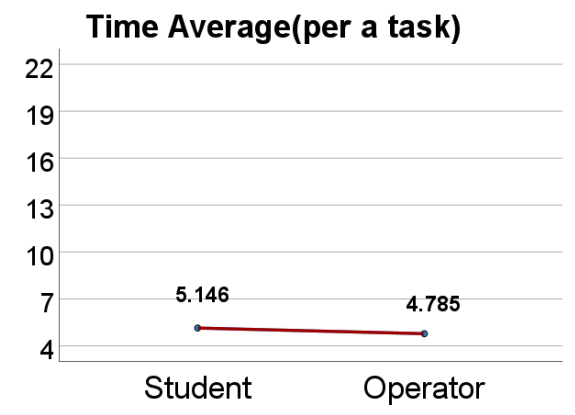






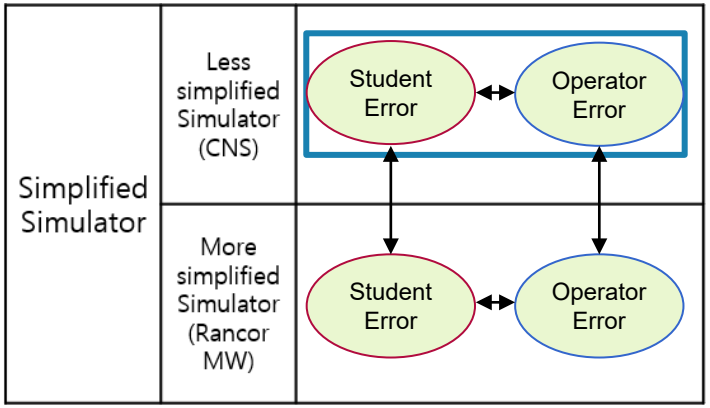
Performance measurement	P-Value
MCH	0.001
SART	0.026
Error rate	0.046
Per a task time(sec)	0.201

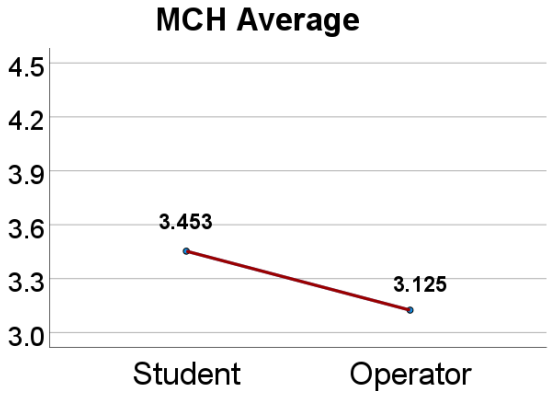


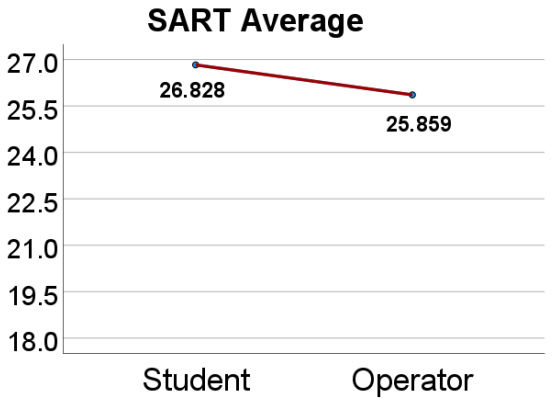


4. Human Performance Analysis

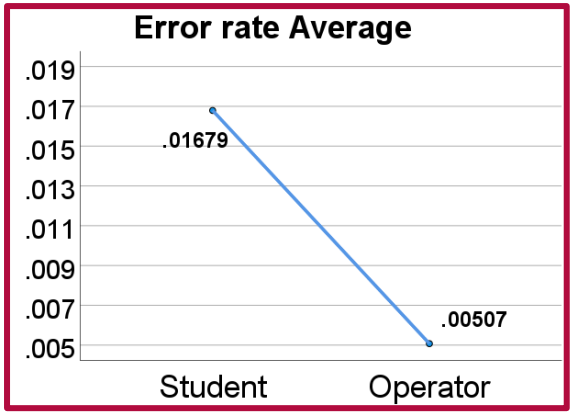
▶ CNS, Between Subjects (2021-2022)

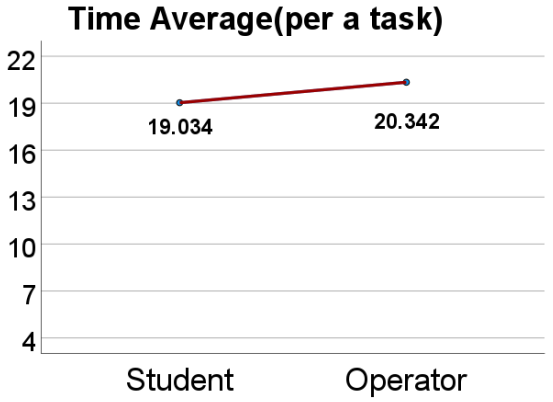






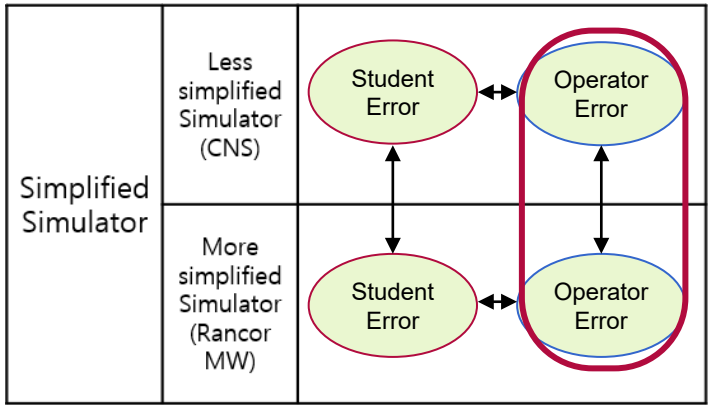
Performance measurement	P-Value
MCH	0.320
SART	0.516
Error rate	0.001
Per a task time(sec)	0.449

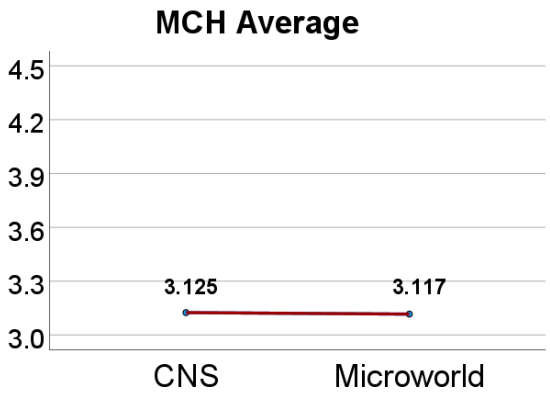


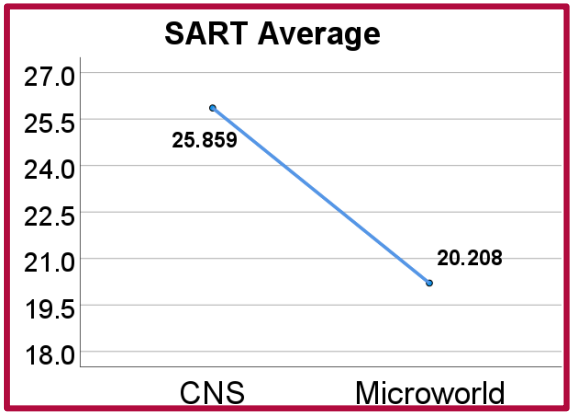


4. Human Performance Analysis

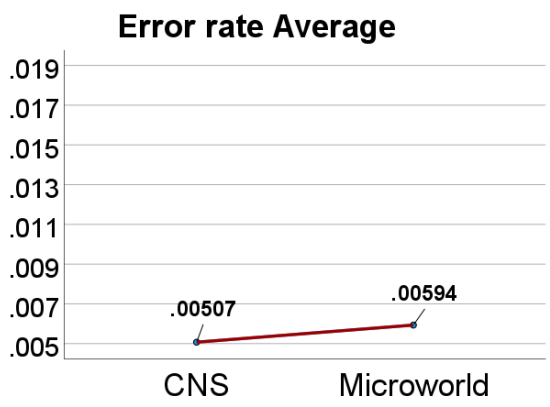
Operators, Between Simulators

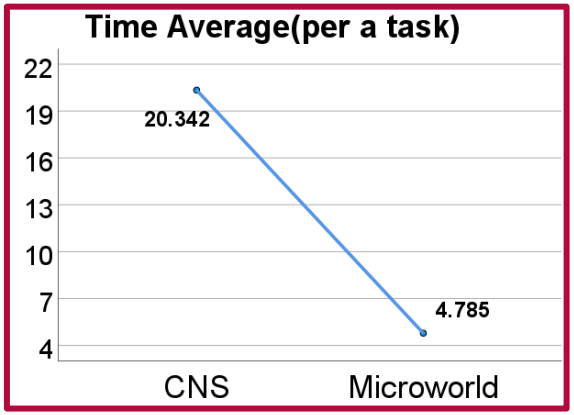






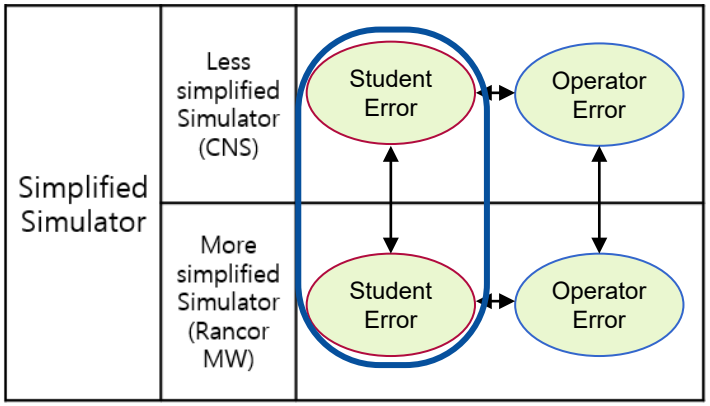
Performance measurement	P-Value
MCH	0.970
SART	0.000
Error rate	0.551
Per a task time(sec)	0.000

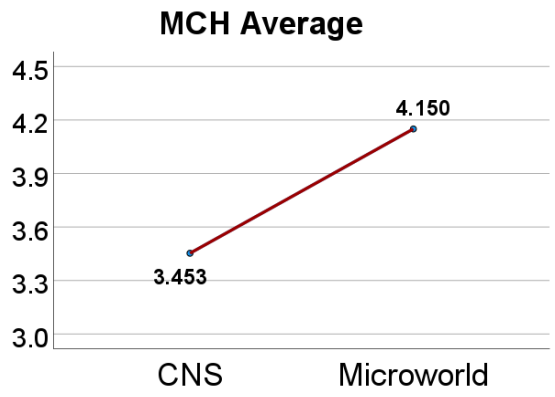


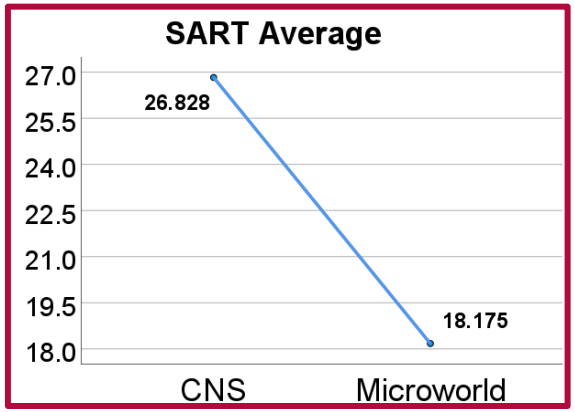


4. Human Performance Analysis

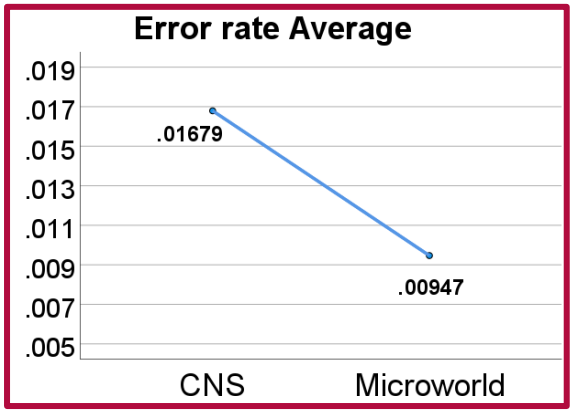
▶ Students, Between Simulators

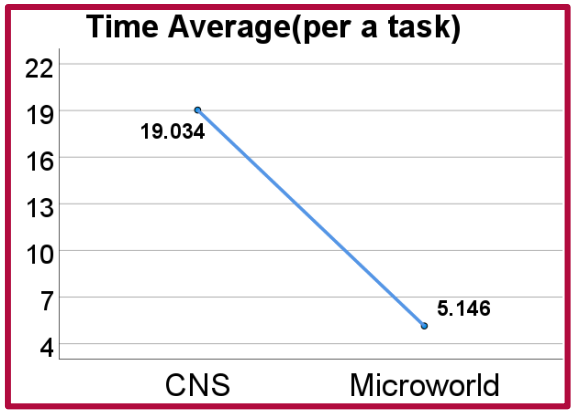






Performance measurement	P-Value
MCH	0.101
SART	0.000
Error rate	0.025
Per a task time(sec)	0.000





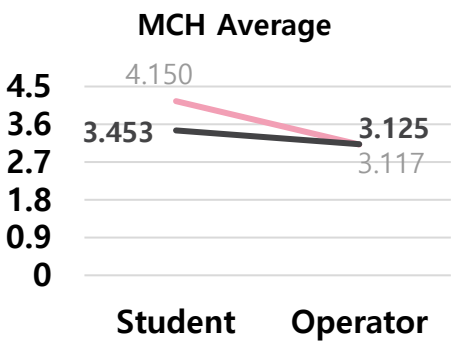
4. Human Performance Analysis

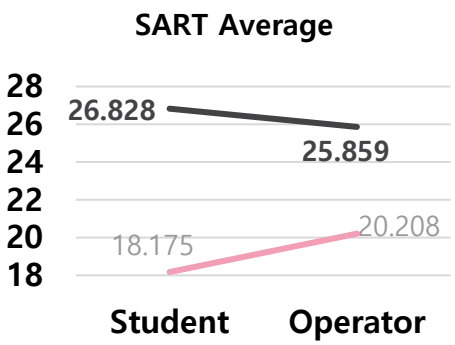
▶ Data Integration

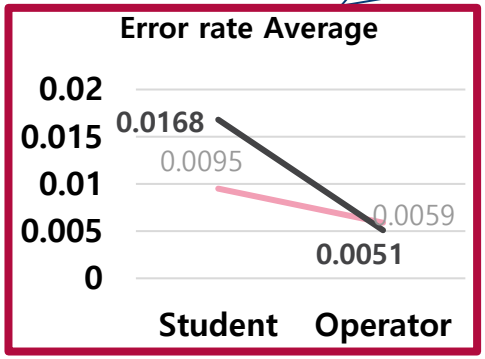
– Microworld, - CNS

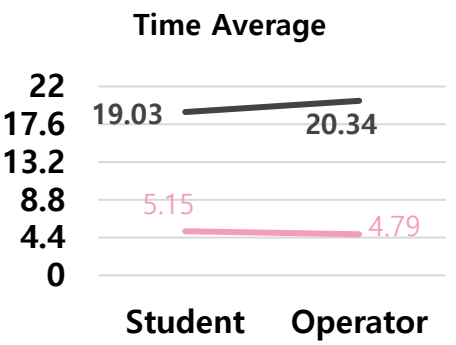
✓ Interaction
- The more experienced the operator, the less the error rate is affected by increasing simulator complexity.

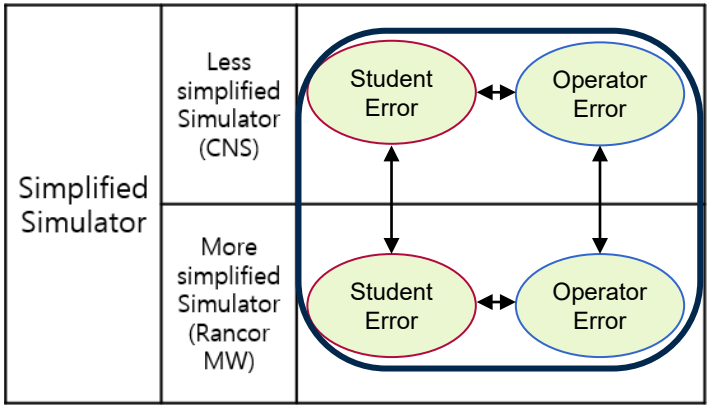
Operators were more tolerant to the complexity.











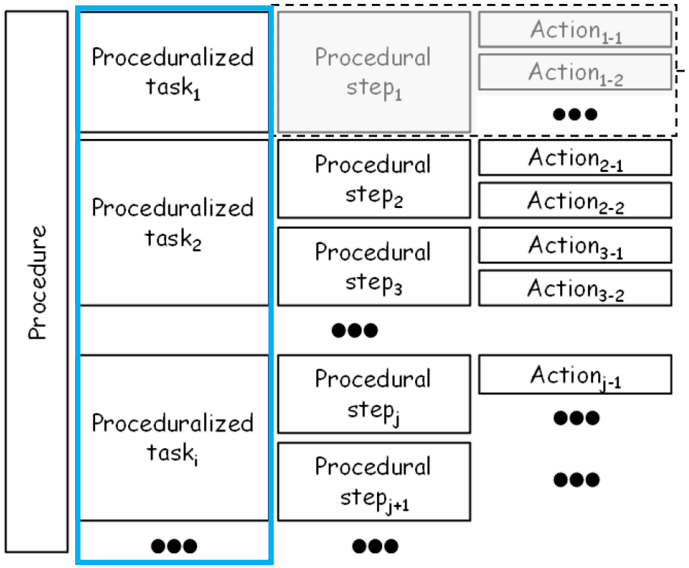
Average	Depending on operator expertise		Depending on simulator complexity	
	Student	Operator	CNS	Rancor MW
MCH	3.80	3.12	3.29	3.63
SART	22.50	23.03	26.34	19.19
Error rate	0.0132	0.0056	0.0109	0.0077
Per a task	12.09	12.56	19.69	4.97

• The red box means the P-Value < 0.05 (i.e., has a statistically significant difference)

5. TACOM Analysis

What is the TAsk COMplexity (TACOM) method ?

- A method for quantifying the complexity of proceduralized tasks



Action/Expected response	Expected response not obtained
1.0 Verify the water level of Tank_1 is less than 70%	1.0 **IF** the water level of Tank_1 exceeds 70%, **THEN** perform one of the following: a. Increase outflow from Tank_1 • Close CV_2 • Open CV_1 b. Provide bypass line

Park, J., 2009. The complexity of proceduralized tasks, Springer-Verlag, Berlin.

Complexity dimension	Definition	Related complexity factor
Task scope (TS)	Representing the breadth, extent, range, or general size of a task being considered	SIC and SSC
Task structurability (TR)	Representing whether or not the sequence and the relationship between subtasks are well structured	SLC and AHC
Task uncertainty (TU)	Representing the degree of predictability or confidence in a task	EDC

Complexity factor	Sub-measure	Physical meaning
Step information complexity	SIC	Complexity due to the amount of information to be processed by human operators
Step size complexity	SSC	Complexity caused by the number of actions to be conducted by human operators
Step logic complexity	SLC	Logical complexity originated from the sequences of actions to be followed by human operators
Abstraction hierarchy complexity	AHC	Complexity resulted from the amount of domain knowledge required by human operators
Engineering decision complexity	EDC	Complexity varied with respect to the amount of cognitive resources required by human operators, which is needed to establish an appropriate decision criterion

$$TACOM = \{0.621 \cdot (TS)^2 + 0.239 \cdot (TR)^2 + 0.140 \cdot (TU)^2\}^{1/2}$$

$$TS = 0.716 \cdot SIC + 0.284 \cdot SSC$$

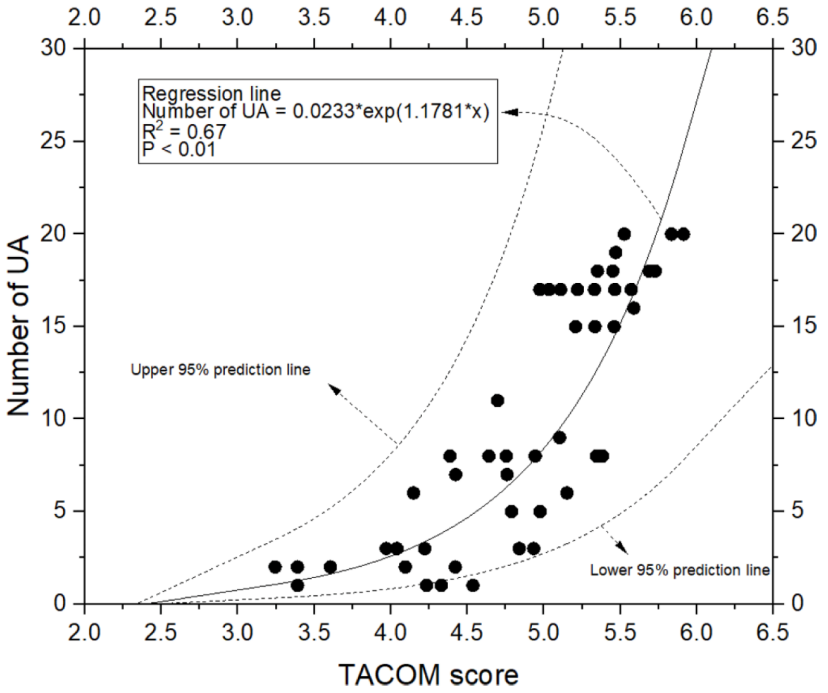
$$TR = 0.891 \cdot SLC + 0.109 \cdot AHC$$

$$TU = EDC$$

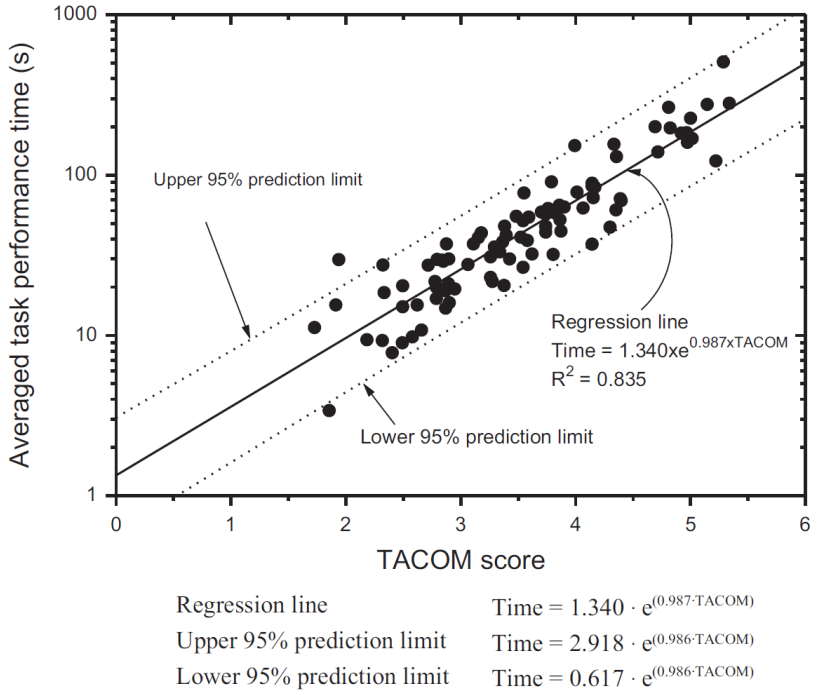
5. TACOM Analysis

Application of the TACOM Method

- Previous studies on relationship between TACOM scores and error/time based on full-scope data (i.e., HuREX)



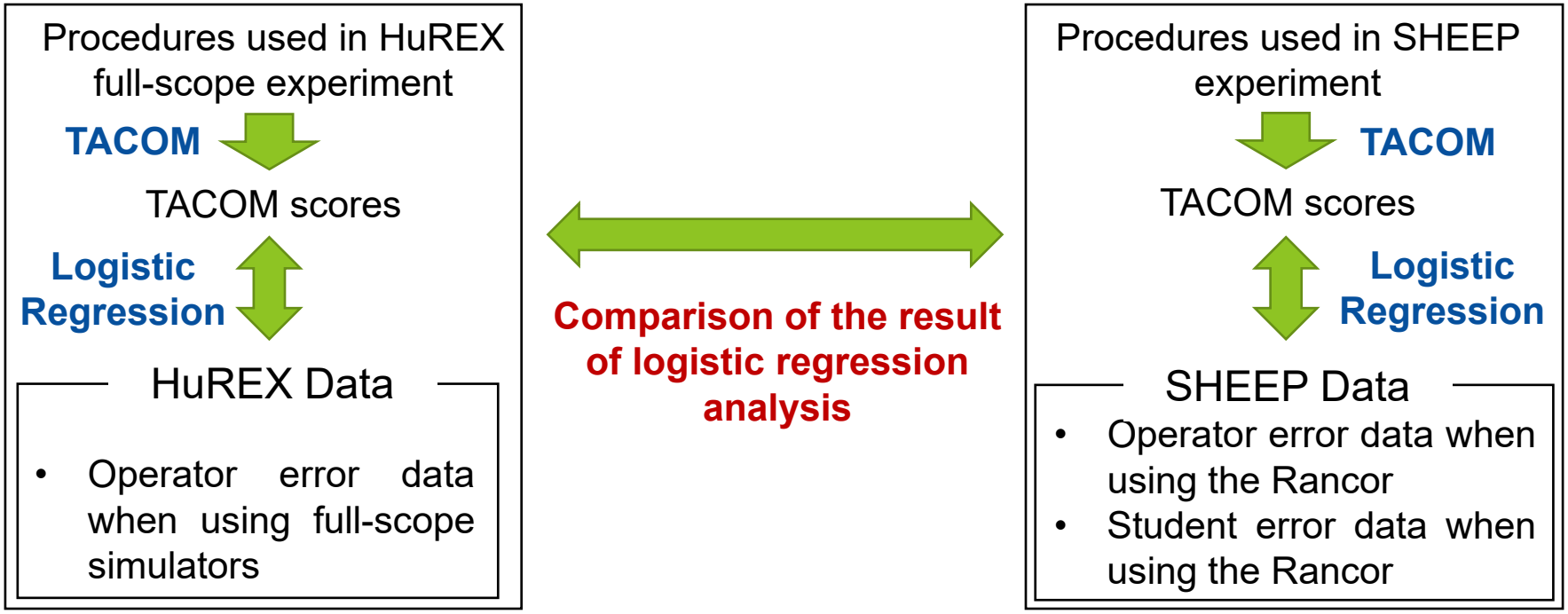
Jang, Inseok, Yochan Kim, and Jinkyun Park. "Investigating the effect of task complexity on the occurrence of human errors observed in a nuclear power plant full-scope simulator." *Reliability Engineering & System Safety* 214 (2021): 107704.



Park, Jinkyun. "Investigating the TACOM measure as a general tool for quantifying the complexity of procedure guided tasks." *Reliability Engineering & System Safety* 129 (2014): 66-75.

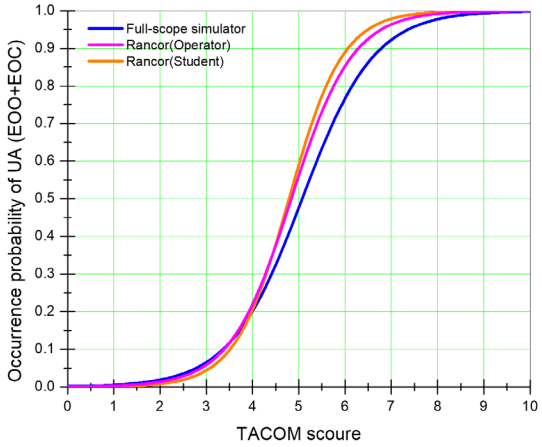
5. TACOM Analysis

Method

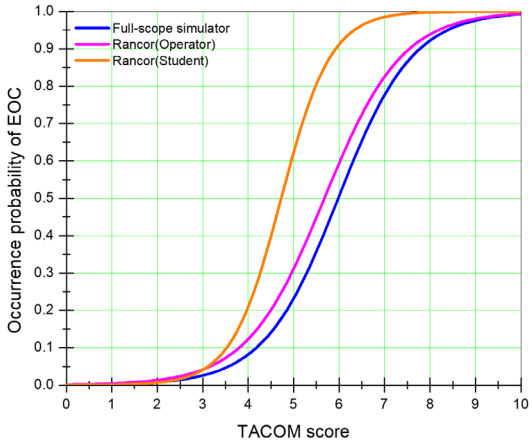


5. TACOM Analysis

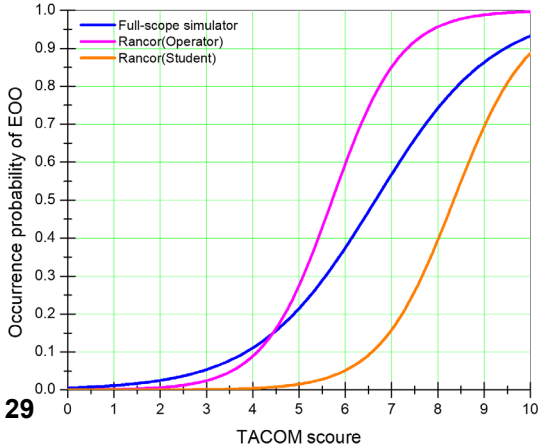
Insights



- Chance of UA occurrences generally goes up along with the increase of TACOM scores.
- The occurrence probability of UAs observed from the Rancor is similar to that of the full-scope simulator (digital MCRs).



- The Logistic regression analysis result of the full-scope simulator is similar to that of operators in the Rancor experiment.
- The Logistic regression analysis result of the full-scope simulator and that of students in the Rancor experiment quite resemble each other.



- The effects of TACOM scores on the changes of occurrence probabilities are not homogeneous with respect to who carried out the required tasks.
- The EOO probabilities when operators use the Rancor are higher than those from the full-scope study.
- The EOO probabilities when students use the Rancor are lower than those from the full-scope study.

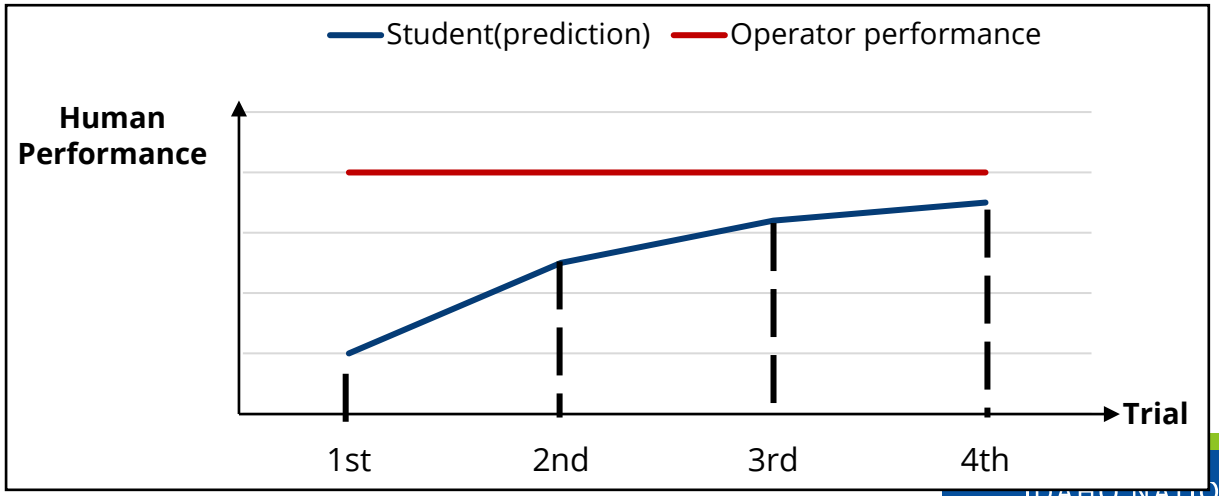
6. Learning Effect Analysis

Additional Experiment for Investigating Learning Effects

- To find out 1) how much training or education is required to collect HRA data from non-experts (i.e., students) and 2) how much differences there are in human performance measures between students and professional operators when using Rancor

Longitudinal Experiment

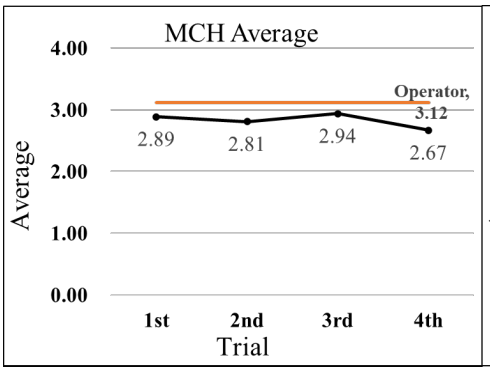
- Four experiment trials with two weeks interval
- Sixteen undergraduate students majoring nuclear engineering at Chosun University
- Totally four scenarios randomly selected from the ten Rancor scenarios
- Four human performance (workload, situation awareness, time and error)
- Average Comparison, Trend Analysis, Tukey's Test, Scheffé's Test

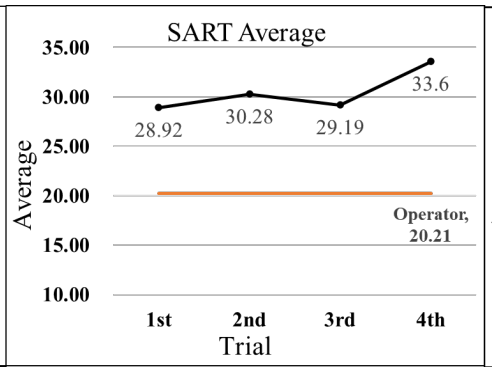


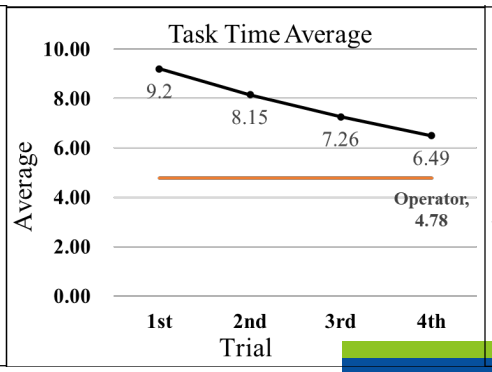
6. Learning Effect Analysis

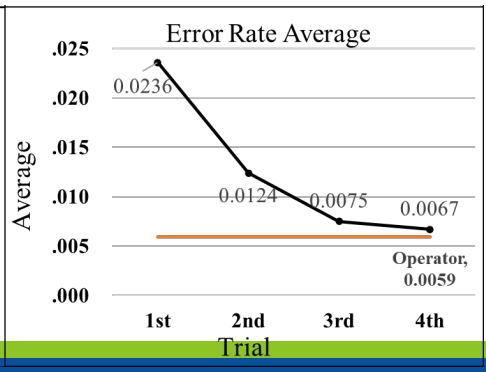
Results

- Overall, the learning effect of human performance was confirmed due to repeated performance.
- Due to the learning effect, students' human performance approaches the actual operator.
  - The workload that students feel subjectively is decreasing and statistically the same as the operator level.
  - The degree of situational awareness that students feel is subjective is on the increase and statistically higher than the operator's level.
  - The students' time completed for the task is decreasing, but statistically, it has not reached the level of the operator.
  - The error rate of students is continuously decreasing and gradually reaching the level of operators. From the second trial, it is statistically equivalent to an operator.



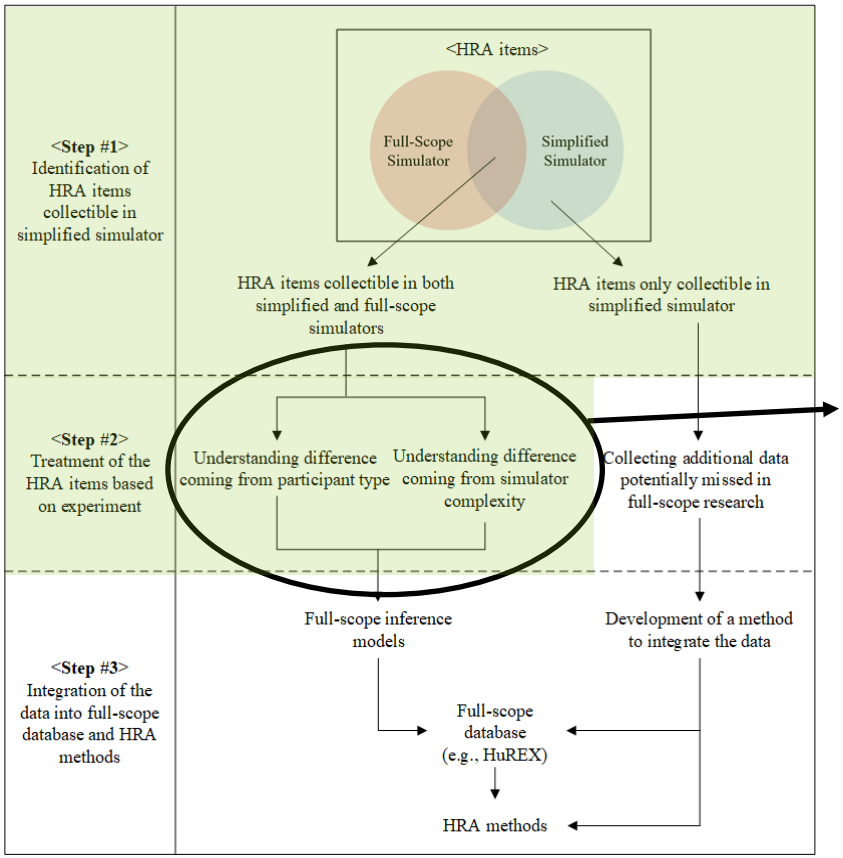


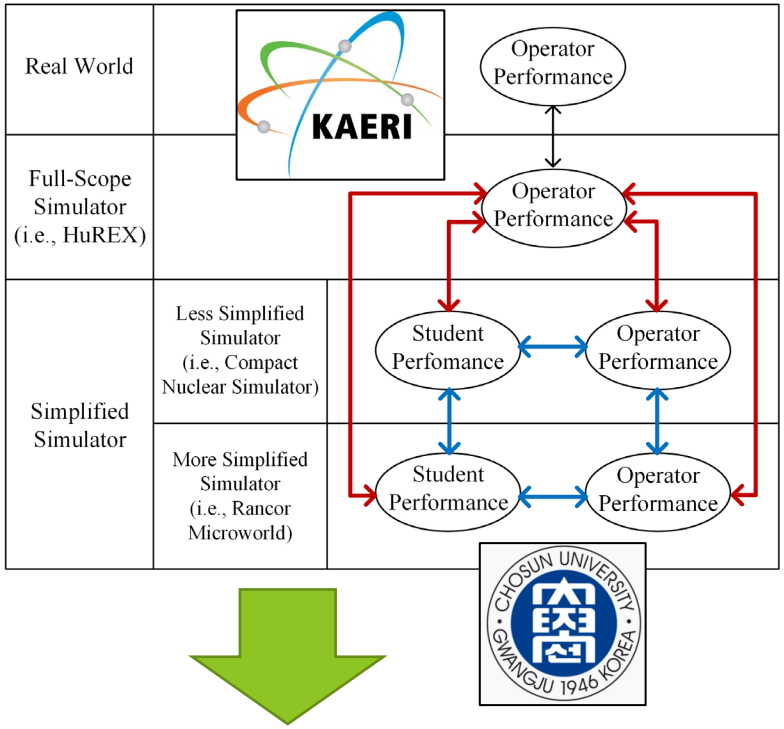




7. Future Work

Summary





- **HuREX Analysis**
- **Human Performance Analysis**
- **TACOM Analysis**
- **Learning Effect Analysis**

7. Future Work

Summary

- Journal Papers
  - Park, J. et al. “A Framework to Collect Human Reliability Analysis Data for Nuclear Power Plants Using a Simplified Simulator and Student Operators.” *Reliability Engineering & System Safety* (2022): 108326.
  - Park, J., et al. “Analysis of Human Performance Differences between Students and Operators When Using the Rancor Microworld Simulator.” *Annals of Nuclear Energy*, 180 (2023) 109502.
  - Yang, T. et al, “Operator Validation Studies Using Simplified Simulators: Analysis of Human Performance on Expertise and Simulator Complexity”, Working.
  - Dr. Park & Jang ?

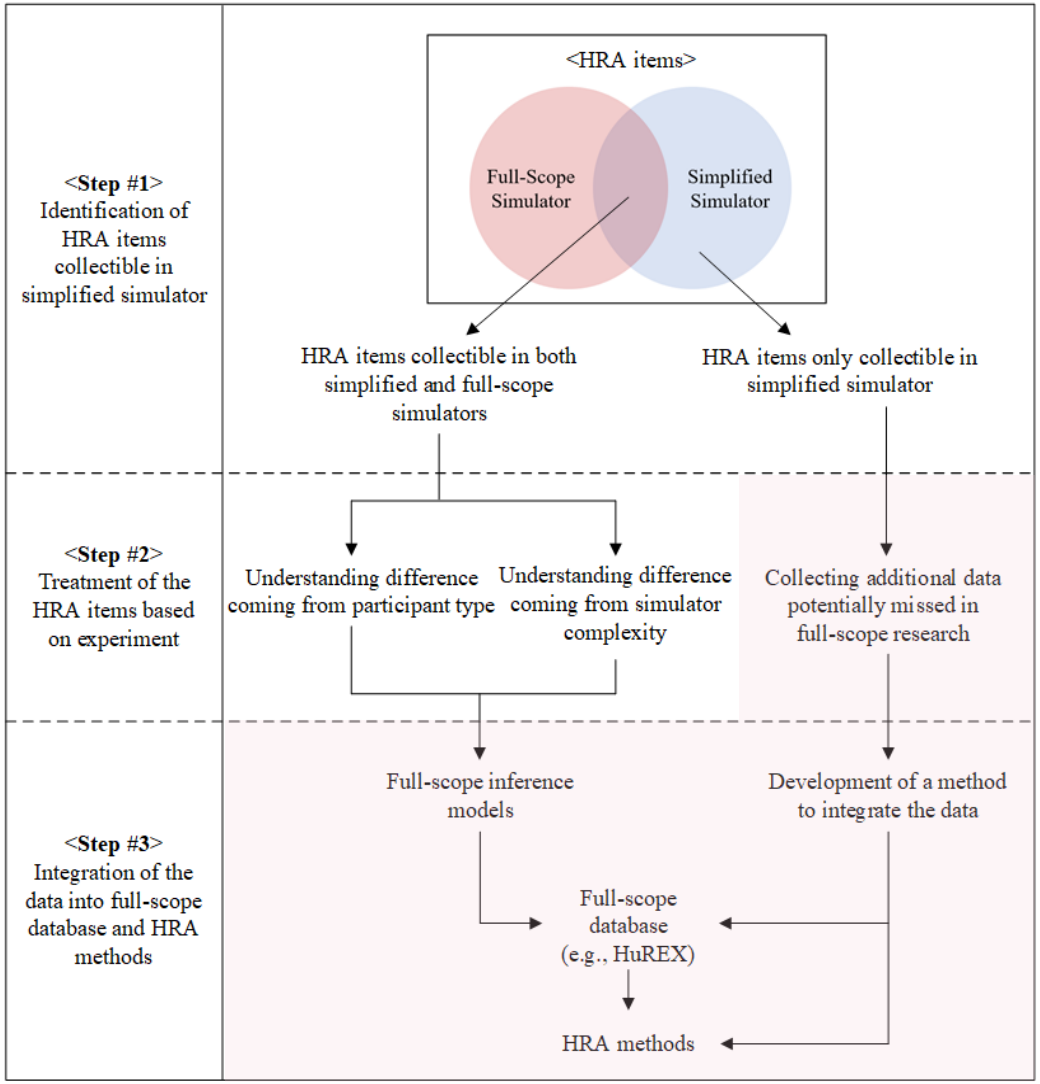
7. Future Work

Summary

- Conference Papers
  - Park, J. et al. “Identification of Collectible Items in the Rancor Microworld Simulator Compared to Full-scope Studies”, 11th International Conference on Applied Human Factors and Ergonomics, July 16 – 20, 2020.
  - Park, B. et al. “Comparison of Human Performance between Operators and Students Using Rancor Microworld Simulator: A Preliminary Result”, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, July 8 - 10, 2020.
  - Park, J. et al. “An Empirical Study on the Use of the Rancor Microworld Simulator to Support Full-scope Data Collection”, Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference, Venice, Italy, November 1 – 5, 2020.
  - Choi, J. et al. “An Experimental Investigation of Human Performance Differences Depending on Simulator Complexity”, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 13-14, 2021.
  - Park, B. et al. “An Experimental Analysis on the CNS Simulator: A Comparison of Human Performance Between Operators and Students”, Transactions of the Korean Nuclear Society Autumn Meeting, Changwon, Korea, October 21-22, 2021.
  - Yang, T. et al. “An Experimental Analysis of Human Performance According to the Simulator Complexity”, 5th International Conference on System Reliability and Safety, Palermo, Italy, November 24-26, 2021.
  - Park, J. et al. “A Comparison of Human Error Probabilities Collected from the HuREX and SHEEP Frameworks”, 2021 American Nuclear Society Winter Meeting and Technology Expo, Washington, DC, November 30 – December 3, 2021.
  - Yang, T. et al. “Human Performance Analysis Depending on Expertise and Simulator Complexity”, 2022 American Nuclear Society Annual Meeting, Anaheim, CA, Jun 12-16, 2022.
  - Park, J. et al., “A framework to integrate HRA data obtained from different sources based on the complexity scores of proceduralized tasks”, Probabilistic Safety Assessment and Management PSAM 16, June 26 – July 1, Honolulu, Hawaii, 2022, Submitted.
  - Yang, T. et al. “An Experimental Investigation of Students’ Learning Effects When Using a Simplified Nuclear Simulator”, 13th Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies (NPIC&HMIT 2023), Submitted.

7. Future Work

What's Next ?

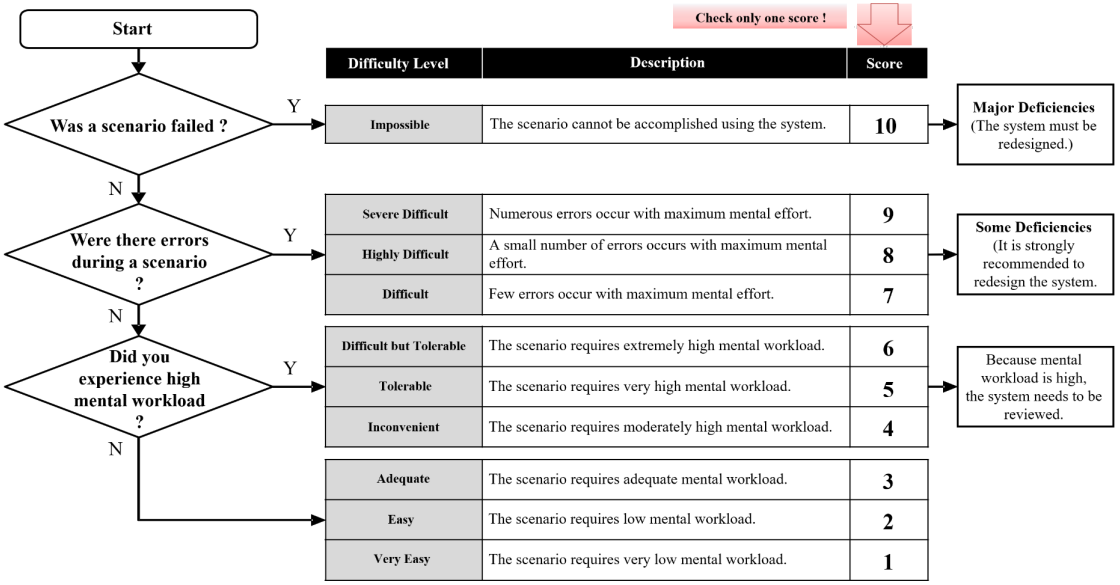


Idaho National Laboratory

2. The SHEEP Framework

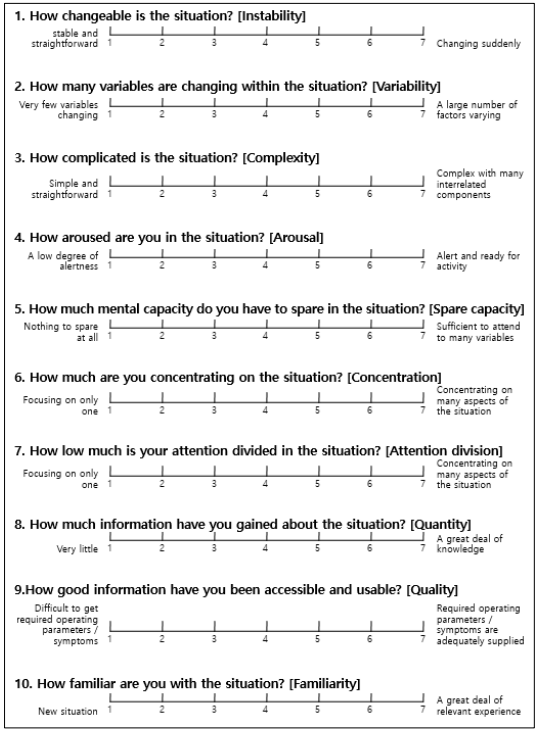
▶ Step #2: Treatment of the HRA items based on experiment

- Human Performance (Cont'd)
  - **Workload**: MCH Scores
  - **Situation Awareness**: SART Scores



Difficulty Level	Description	Score	
Impossible	The scenario cannot be accomplished using the system.	10	Major Deficiencies (The system must be redesigned.)
Severe Difficult	Numerous errors occur with maximum mental effort.	9	Some Deficiencies (It is strongly recommended to redesign the system.)
Highly Difficult	A small number of errors occurs with maximum mental effort.	8	
Difficult	Few errors occur with maximum mental effort.	7	
Difficult but Tolerable	The scenario requires extremely high mental workload.	6	Because mental workload is high, the system needs to be reviewed.
Tolerable	The scenario requires very high mental workload.	5	
Inconvenient	The scenario requires moderately high mental workload.	4	
Adequate	The scenario requires adequate mental workload.	3	
Easy	The scenario requires low mental workload.	2	
Very Easy	The scenario requires very low mental workload.	1	

Modified Cooper-Harper (MCH)



Situation Awareness Rating Technique (SART)

2. The SHEEP Framework

▶ Step #2: Treatment of the HRA items based on experiment

- Human Performance (Cont'd)
  - **Error**: Error Rate
    - Error is defined as deviation from expected performances.
    - Same rules used in the HuREX data collection are applied.
    - The HuREX analysts participated in the error analysis.
  - **Time to Completion**: Average Time to Complete A Step / An Instruction / A Task
    - Analyzed based on procedures and video records

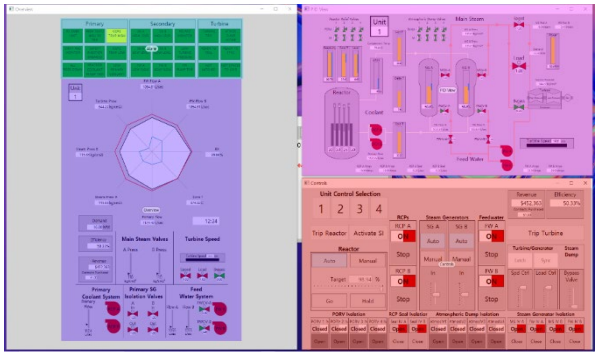
	Scenario	Type of Error	Stu.01	Sum	Stu.02	Sum	Stu.03	Sum	Stu.04	Sum
Non-event	Start-up(#1)	RP-Step(EOC)	2	3		0		1		0
		Ex-Continuous(EOC)					1			
		Ex-Dynamic(EOC)	1							
		RP-Step(EOO)								
	Shutdown(#2)	Ex-Continuous(EOC)		0		0		0		0
		Ex-Dynamic(EOC)								
	Manual Rod during Start_up(#3)	Ex-Dynamic(EOC)	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)								

Procedure	Step	Step Num.	Task	Task-Verb	Error	Time	Description
OP-003	3. Primary side coolant injection	Pre-C	Reactor must be provided with adequate coolant to prevent overheating for reactor core. Primary side coolant flow should be maintained at least 127.0 L/sec.			22:24:40	
		3.1	Activate the RCP.			22:24:45	
		3.1.1	·Click RCP A start button.	Perform		22:24:48	
		3.1.2	·Click RCP B start button.	Perform	EOO/R	22:24:50	1. Time: 22:24:50 2. Current State: During the Start-up, RCP B not operation. 3. Action: He didn't click the RCP B start button 4. Result: RCP B not started 5. Description: Recovery by operation knowledge
		3.2	See below to determine if the primary coolant is sufficient.			22:24:50	
		3.2.1	·Low Primary Coolant alarm off confirmation.	Check		22:24:51	
		3.2.2	·Primary Flow indicator is higher than 508.0L / sec	Check		22:24:53	
		3.3	If the above conditions are satisfied, the process moves to step 4.	Move		22:24:55	
	4. Reactivity Control	4.1	To increase Reactivity to 20% using Manual, go to the OP-004 procedure.	Check/Move		22:25:00	

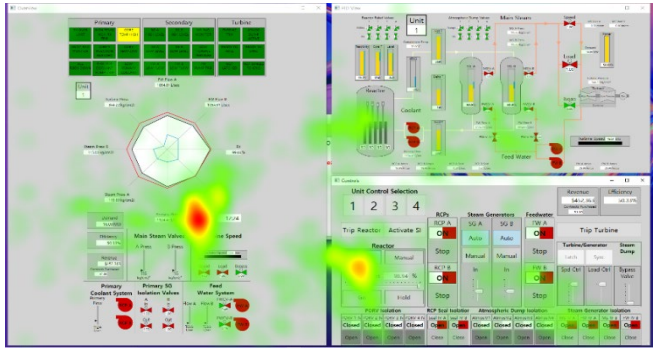
2. The SHEEP Framework

▶ Step #2: Treatment of the HRA items based on experiment

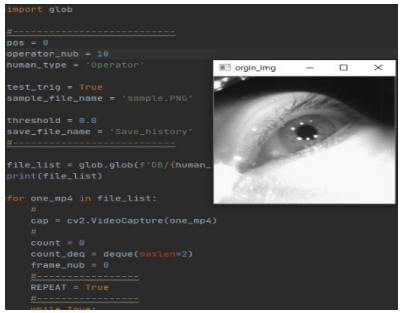
- Human Performance (Cont'd)
  - **<u>Eye Movements</u>**: Eye Fixation Count / Duration Per Task, Blink Rate, Heatmap Over Area of Interests (AOI)
    - ➢ Fixation duration and counts, eye blinking, and gaze movement
    - ➢ Tobii Pro Glasses 2
    - ➢ Four Areas of Interest (AOIs): Alarm, Overview, P&ID, Control Area



<AOIs>



<Heatmap>



<Eye Blinking Rate>

  - **<u>Number of Manipulations</u>**: Number of Manipulations per Task / per Scenario Completion Time
    - ➢ Estimated from simulator log data

{"EventType":"Simulation", "Tag":"Start", "Time":0, "RX":98.2692294477296, "MW":54.5491744984957}
{"EventType":"Alarm", "Tag":"AtmosDumpActive", "State":"Cleared", "Unit":1, "Time":1.0093952, "RX":98.2286081374419, "MW":54.5491744984957}
{"EventType":"Alarm", "Tag":"CoreHighTemp", "State":"Alarmed", "Unit":1, "Time":2.0098807, "RX":98.2286081374419, "MW":54.840732182516}
{"EventType":"ControlAction", "Tag":"SGSGAin", "Mode":"manual", "Value":"0.461748397052678", "Time":2.0098807, "RX":98.0600762918027, "MW":54.7726059086581}
{"EventType":"ControlAction", "Tag":"SGSGBin", "Mode":"manual", "Value":"0.461748397052678", "Time":2.0098807, "RX":98.0600762918027, "MW":54.7726059086581}
{"EventType":"ControlAction", "Tag":"SGSGAin", "Mode":"manual", "Value":"0.461176073053509", "Time":4.0130494, "RX":98.9049985703981, "MW":54.8454880458299}
{"EventType":"ControlAction", "Tag":"SGSGBin", "Mode":"manual", "Value":"0.461176073053509", "Time":4.0130494, "RX":98.9049985703981, "MW":54.8454880458299}