INL/CON-20-57751-Revision-0

An Empirical Study on the Use of the Rancor Microworld Simulator to Support Full-scope Data Collection

November 2020

Changing the World's Energy Future

Jooyoung Park, Thomas A Ulrich, Ronald Laurids Boring PhD, Jonghyun Kim, Sungheon Lee, Bumjun Park

INL/CON-20-57751-Revision-0

An Empirical Study on the Use of the Rancor Microworld Simulator to Support Full-scope Data Collection

Jooyoung Park, Thomas A Ulrich, Ronald Laurids Boring PhD, Jonghyun Kim, Sungheon Lee, Bumjun Park

November 2020

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

An Empirical Study on the Use of the Rancor Microworld Simulator to Support Full-Scope Data Collection

Jooyoung Park, Thomas A. Ulrich, Ronald L. Boring

Human Factors and Reliability Department, Idaho National Laboratory, U.S.A. E-mail: {Jooyoung.park, Thomas.ulrich, Ronald.boring}@inl.gov

Sungheon Lee, Bumjun Park, Jonghyun Kim

Department of Nuclear Engineering, Chosun University, Republic of Korea. E-mail: {leesh0867, pbj1218}@chosun.kr, jonghyun.kim@chosun.ac.kr

Lack of data is a major challenge in human reliability analysis (HRA). Accordingly, several institutes and researchers have tried to collect HRA data from different data sources, such as actual historical measurements, expert judgements, and simulator studies. While the most recent studies predominantly focus on collecting data using full-scope simulators with actual operators, Idaho National Laboratory (INL) now collects HRA data using the Rancor Microworld simulator, a simplified simulator, with student participants. Full-scope studies are known to pose intrinsic challenges for securing adequate data. This is due to many reasons, including the high cost of experiments and the necessity for cooperation with actual operators. INL aims to infer actual-operator data via a full-scope simulator using Microworld data and student subjects, as well as additional data perhaps missed in the full-scope research. As a first step toward achieving this goal, this paper proposes an experimental plan for investigating differences in human performance between individuals in two groups: 1) actual operators and 2) students using the Rancor Microworld simulator. A randomized factorial experiment design was developed with two independent variables: type of scenario and type of subject. Six human performance measurements—1) time, 2) error, 3) workload, 4) situational awareness, 5) attention patterns, and 6) number of manipulations—were selected. A couple scenarios and related procedures to be simulated by Rancor Microworld were then developed.

Keywords: Probabilistic safety assessment, human reliability analysis, human performance, data collection, simulator study, Rancor Microworld.

1. Introduction

Lack of data is a major challenge in human reliability analysis (HRA) (Park, Lee, Jung, & Kim, 2017; Swain & Guttmann, 1983). To date, the most broadly used HRA methods—such as the Standardized Plant Analysis Risk HRA (Gertman, Blackman, Marble, Byers, & Smith, 2005)—depend on a dataset provided by the Technique for Human Error Rate Prediction (Swain & Guttmann, 1983). Accordingly, to update these data, several institutes and researchers tried to collect HRA data from different data sources, such as actual historical measurements, expert judgements, and simulator studies (Jung, Park, Kim, Choi, & Kim, 2020).

The majority of recent HRA studies focus on collecting data using full-scope simulators with actual operators. But in fact, full-scope studies pose several intrinsic challenges for securing adequate data. A full-scope study entails high expense in securing a full-scope facility and numerous actual operators. Many experts in operating nuclear power plants (NPPs) also participate in the research. Because this work is relatively resource-intensive and time-consuming, in addition to presupposing utilities' cooperation in partially releasing collected data, it is strictly limited to those few organizations able to satisfy such conditions.

In keeping with the need for human reliability data sources, Idaho National Laboratory (INL) began collecting HRA data via the Rancor Microworld simulator, a simplified simulator, with student participants. In this way, INL aims to infer actual-operator data via the full-scope simulator by using Microworld data and student subjects, in addition to data perhaps missed in the full-scope research. As a first step toward achieving this goal, this paper proposes an experimental plan for investigating differences in human performance between actual operators and students using the Rancor Microworld simulator. A randomized factorial experiment design was developed with two independent variables: type of scenario and type of subject. Six human performance measurements—1) time, 2) error, 3) workload, 4) situational awareness, 5) attention patterns, and 6) number of manipulations—were selected. A couple scenarios and related procedures to be simulated by Rancor were then developed.

Proceedings of the 30th European Safety and Reliability Conference and
the 15th Probabilistic Safety Assessment and Management Conference.
Edited by Piero Baraldi, Francesco Di Maio and Enrico Zio

ISBN: 981-973-0000-00-0 :: doi: 10.3850/981-973-0000-00-0 esrel2020psam15-paper

2. Experimental Design

In this study, a randomized factorial experiment compared human performance between actual operators and students. Table 1 shows the experimental design, composed of two independent variables: type of subject and type of scenario. Details of the experimental design are described in the following sections.

Table 1. Randomized factorial experiment design.

Type of Scenario	Type of Subject	
	Actual Operator	Student
Non-event		
Event		

2.1 *Independent Variables*

2.1.1 *Type of subject*

This variable is divided into two groups: actual operators and students. The former consists of licensed operators currently employed at Korean NPPs, while the latter is composed of undergraduate and graduate students at nuclear engineering departments. These students have at least a basic knowledge of NPP systems and operations.

2.1.2 *Type of scenario*

Scenarios are categorized as either non-event or event scenarios. Non-event scenarios relatively align with work performed during normal operating states such as start-up, shut-down, or full-power operations. In such a scenario, subjects may not feel the intense stress or time pressure involved in event scenarios. On the other hand, event scenarios consist of multiple critical actions needing to be finished within a limited timeframe, and that positively or negatively affect the future state of the plant. Abnormal or emergency situations are often examples of event scenarios.

This variable may help shed light on the feasibility of using simulator studies to collect event scenario-based data. To date, data from simulator studies and experimental research are considered a challenge in terms of fidelity (i.e., the degree to which experimental environments correspond to actual conditions).

2.2 *Experiment Scenario*

Several scenarios were developed for achieving the experiment goal. They are relatively simple compared to scenarios for full-scope simulators. Table 2 lists the experiment scenarios and related procedures that are tested and ready to be carried out. Non-events include start-up and shut-down scenarios, whereas events consist of abnormal cases and emergency scenarios.

Each scenario is terminated when the subjects complete a predetermined procedure or reach a specific goal. Non-event scenarios end when reactor power reaches a predetermined target (i.e., 0% or 100%). Event scenarios end when subjects successfully perform all procedural steps or instructions, and parameters such as core temperature are stably maintained.

Table 2. List of experiment scenarios and procedures.

Type of Scenario	Specific Scenario	Procedure
Non-event	Start-up operation (0% to 100%)	OP-001 (Start-up)
	Shut-down operation (100% to 0%)	OP-002 (Shut-down)
	Manual reactor control in part of a start-up operation	OP-001 (Start-up) and OP-010 (Manual reactor control)
	Manual feedwater control in part of a start-up operation	OP-001 (Start-up) and OP-011 (Manual feedwater control)
Event	Reactor coolant pump failure during full-power operation	AOP-001 (Rapid shutdown)
	Control rod failure during full-power operation	AOP-001 (Rapid shutdown)
	Feedwater pump failure during full-power operation	AOP-001 (Rapid shutdown)
	Abnormal turbine trip during full-power operation	AOP-001 (Rapid shutdown)
	Steam generator tube rupture with an indicator failure for the steam generator level	EOP-E-3 (SGTR)
	Loss of feedwater	EOP-E-2 (LOFW)

2.3 *Human Performance Measurements*

In this experiment, six human performance measurements—1) time, 2) error, 3) workload, 4) situational awareness, 5) attention patterns, and 6) number of manipulations—are given for each scenario. This section details each of these measurements.

2.3.1 *Time*

Time-related information collected in the experiment includes the time to complete a scenario, the average time to complete a step, and the average time to complete an instruction. A procedure consists of steps that can further be broken down into individual instructions, each usually including an operator action in the Microworld procedure.

2.3.2 *Error*

Errors indicate when the operator's task performance deviates from the procedure. This includes errors of omission and commission, and it takes into account both the number and rate of errors. The error rate is calculated by dividing the number of errors by the total number of tasks in each scenario.

2.3.3 *Workload*

This study considers two different approaches—Modified Cooper-Harper (MCH) rating scale (Cummings, Myers, & Scott, 2006) and an eye-tracker—to estimate workload. The MCH rating scale was originally developed by the aviation industry to estimate operators' psychological and physical workloads. Additionally, it provides design recommendations depending on the rating scale. It evaluates workloads based on responses to post-scenario questionnaires. The second approach is to use an eye-tracker. Certain research (Coral, 2016; Telford & Thompson, 1933) indicates a relationship between blinking rate and cognitive workload.

2.3.4 *Situational awareness*

Situational awareness is the perception of elements in an environment within a volume of time and space; comprehending the meaning and projecting the status of the elements in the near future (Endsley & Garland, 2000). In this study, the Situation Awareness Rating Technique (SART) (Taylor, 2017) was used to estimate subjects' situational awareness.

2.3.5 *Attention patterns*

This performance measurement, which relies on the eye-tracker system, estimates the proportion that focuses on major information in the microworld interface: alarms, the primary system, the steam generator, the turbine system, etc.

2.3.6 *Number of manipulations*

The number of manipulations refers to how many times the subjects manipulate microworld interfaces. Manipulations include turning pumps, valves, and sliders on or off.

3. Subjects

Table 3 summarizes the experiment subjects. Basically, the Rancor Microworld simulator was designed so a single subject could operate the system. The current plan calls for more than 20 subjects (both actual operators and students) to participate in the experiment. The actual operators will be licensed operators employed at Korean NPPs. The students will be knowledgeable about NPPs and their operation, and will mostly come from universities in Korea.

Table 3. Summary of experiment subjects.

Type of Subject	Number of Subjects	Description
Actual operator	More than 20	Licensed operators employed at Korean NPPs
Student	More than 20	Knowledgeable about NPPs and their operations, or having participated in the undergraduate class, "Reactor Operation and Simulator Training"

4. Facility

The Rancor Microworld simulator (Ulrich, 2017) is used for this experiment. Its simplified simulation environment reproduces important characteristics of real NPP operations. Furthermore, it has been used to examine theoretical and practical design concepts, and provides a graphical user interface enabling researchers to generically create process control systems. The Rancor Microworld simulator was developed based on the simulation's thermo-hydraulics, which followed a gamified Rankin cycle resembling that of a small modular reactor.

Fig. 1 is a screenshot of the Rancor Microworld interface. It consists of three windows: 1) the Overview Window, 2) the Piping and Instrumentation Diagram Window, and 3) the Controls Window. The Overview Window includes general system information such as the alarm panel. The integrated design helps inform operators when certain parameters fall outside the acceptable range. The Piping and Instrumentation Diagram Window shows parameters for things such as water level and whether or not pumps or valves have been turned on and opened. Lastly, the Controls Window pertains to all controllable measures such as buttons and sliders.

The simulator was installed on a laptop dedicated for Microworld experiments only. Therefore, this experiment can be performed wherever a desk, chair, and power source are available. In addition, the laptop enables subjects to operate microworld via touch screen.

5. Data Acquisition

In this study, the majority of data is collected via the aforementioned questionnaires and eye-tracker. Table 4 summarizes the data acquisition methods, their collectable items, and human performance measurements. All items collected from each method are directly linked to human performance data or additional data potentially helpful for understanding analysis results and compiling alternative methods for identifying other significant results.

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

Method	All Items Collected	Human Performance
Questionnaires	General information, Situational awareness scores from SART, Workload from MCH	Situational awareness, Workload
Eye-tracker	Video record, Area of interest, Gaze, Workload (based on blinking data)	Time, Error, Attention patterns, Workload
Microworld	Microworld log data	Number of manipulations

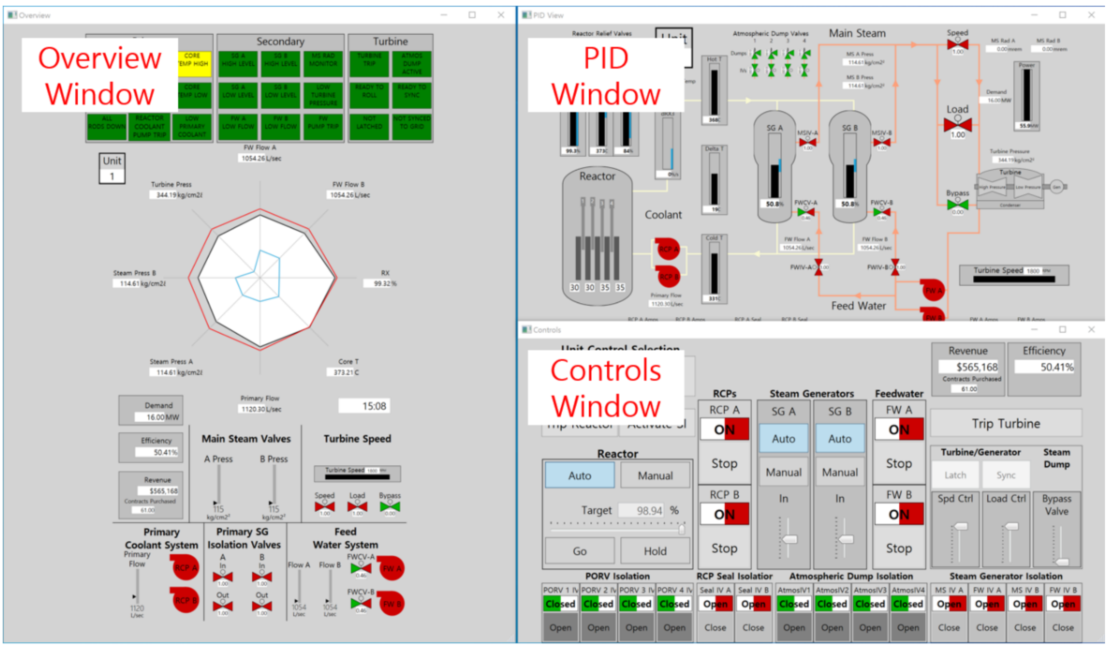

Fig. 1. Rancor Microworld interface.

6. Experiment Procedure

Each subject conducts three different scenarios consisting of non-events or events. Scenarios are randomly selected from among those introduced in Table 2. Termination conditions for each scenario are described in Section 2.2. The time it takes for each subject to participate in an experiment by completing the six scenarios is approximately 1.5 hours.

Before conducting the scenarios, an introductory presentation will be shown to give the subjects an overview of the experiment. The subjects will have enough time to become familiar with the Microworld interfaces.

7. Data Analysis

Data collected from the experiments are analyzed in three ways. First, several statistical analysis methods are applied for the randomized factorial experiment design introduced in Section 2. Representatively, an analysis of variance can be performed to identify significant results between items in each independent variable. Second, an increase trend on the number of trials is compared between operators and students. In the previous study (Ulrich, 2017), operators showed a steeper learning curve in comparison with students. Lastly, workload data collected from the MCH questionnaire and eye-tracker are analyzed.

8. Conclusion

This paper describes an experimental plan for using the Rancor Microworld simulator to investigate differences in human performance between actual operators and students. The major results of the experiment will be presented at the conference.

As a starting point, this study can contribute to INL's research goal of inferring actual-operator data from a full-scope simulator by instead using Microworld data with student subjects and collecting additional data potentially missed in full-scope research.

Acknowledgement

This work of authorship was prepared as an account of work sponsored by Idaho National Laboratory, an agency of the U.S. Government. Neither the U.S. Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe on privately-owned rights. Idaho National Laboratory is a multi-program laboratory operated by Battelle Energy Alliance LLC, for the U.S. Department of Energy under Contract DE-AC07-05ID14517.

References

Coral, M. P. (2016). Analyzing cognitive workload through eye-related measurements: A meta-analysis.

Cummings, M., Myers, K., & Scott, S. D. (2006). Modified Cooper Harper evaluation tool for unmanned vehicle displays. Paper presented at the Conference on Unmanned Vehicle Systems.

Endsley, M. R., & Garland, D. J. (2000). Situation awareness analysis and measurement: CRC Press.

Gertman, D., Blackman, H., Marble, J., Byers, J., & Smith, C. (2005). The SPAR-H human reliability analysis method. U.S. Nuclear Regulatory Commission.

Jung, W., Park, J., Kim, Y., Choi, S. Y., & Kim, S. (2020). HuREX–A framework of HRA data collection from simulators in nuclear power plants. Reliability Engineering & System Safety, 194, 106235.

Park, J., Lee, D., Jung, W., & Kim, J. (2017). An experimental investigation on relationship between PSFs and operator performances in the digital main control room. Annals of Nuclear Energy, 101, 58-68.

Swain, A. D., & Guttmann, H. E. (1983). Handbook of human-reliability analysis with emphasis on nuclear power plant applications. Final report.

Taylor, R. M. (2017). Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In Situational Awareness (pp. 111-128): Routledge.

Telford, C., & Thompson, N. (1933). Some factors influencing voluntary and reflex eyelid responses. Journal of Experimental Psychology, 16(4), 524.

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